Musically Generated Form:
A Means of Translation

Micah Makena Thrasher
December 2012

Submitted towards the fulfillment of the requirements for the Doctor of Architecture degree

School of Architecture
University of Hawai'i

Doctorate Project Committee
Kris Palagi, Chairperson
Byong Won Lee
Chad Hamman

Musically Generated Form: A Means of Translation

Micah Makena Thrasher
December 2012

We certify that we have read this Doctorate Project and that, in our opinion, it is satisfactory in scope and quality in fulfillment as a Doctorate Project for the degree of Doctor of Architecture in the School of Architecture, University of Hawaiʻi at Mānoa.

Doctorate Project Committee

____
Kris Palagi, Chairperson

____
Byong Won Lee

____
Chad Hamman

Contents

Foreword

You are about to embark on a journey through sound: a journey where pure intuition, combined with a diligence to comprehend, has led to the conception of 'sound' ideas – ideas that in turn have an intonation with the harmonies of nature, and resonate with our perception of the world. This investigation uses music as a concept for architectural design in an effort to enrich the intrinsic value of both creative mediums by bringing depth and purpose to their design. Through the overlap of music and architecture, we distinguish the intersections of many other fields, and begin to understand how all things in life coincide in some form or another. I hope that this text will be as much of a learning process for you as it has been for me.

> *"To develop a complete mind: study the science of art; study the art of science. Learn how to see. Realize that everything connects to everything else."* [1]
>
> ~ *Leonardo da Vinci*

[1] Adair, John Eric. "Drift, wait and obey." In *The art of creative thinking how to be innovative and develop great ideas*. London: Kogan Page, 2007. 99.

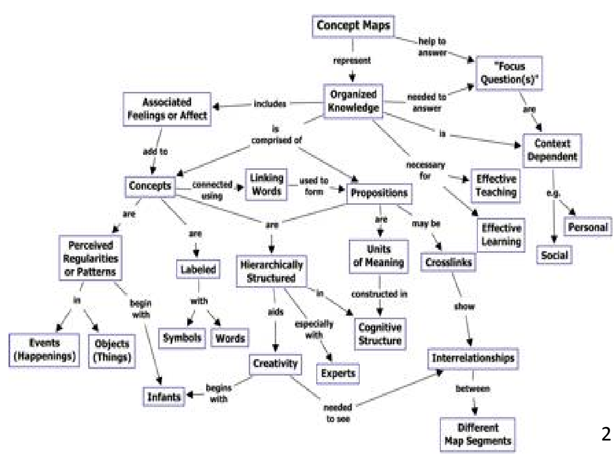
Preface

The Overlap

Why study the correlation between music and architecture? Why not study music and culture, or architecture and the environment? At first thought, the two creative disciplines may appear to be on opposite ends of a spectrum; however, they overlap in many ways, far beyond what the naked eye can see, or what the deaf ear cannot hear.

I believe one of the most provocative aspects of the human psyche is our desire to define everything around us: the all-encompassing world we live in. We have an innate desire to search, discover, and identify all of existence. Through systematic categorization, we strive to pick apart the very fabric of life in a search to describe the multifaceted components that make our world tick.

The figure to the left, from *The Theory Underlying Concept Maps and How to Construct Them*, by J. D. Novak and A. J. Cañas, depicts the degree of our tentative desire to break down and reinforce the knowledge of humanity.



[2]

[2] Novak, Joseph D., and Alberto J. Cañas. "The Theory Underlying Concept Maps and How to Construct and Use Them." Institute for Human and Machine Cognition. http://cmap.ihmc.us/publications/researchpapers/theorycmaps/theoryunderlyingconceptmaps.htm (accessed November 20, 2010).

The irony that this is a concept map, used to explain how concept maps work, further exemplifies our evocative vigor to define the substance of life.

Humans have developed a multitude of languages, all of which are used to describe and explain the world around us: spoken or written languages, mathematics, physics, drawings, paintings, sculptures, music, architecture – all of these languages are tools that aid in describing not only the physical realm we live in, but also the mental and emotional states that make us human. These languages have rules that govern them; and in turn, language is utilized to define the parameters of a given subject matter and articulate our knowledge therein. We cannot justify languages or theories without rules and concise narratives to prove that our ideas and thoughts are accurate; it is at this point our definitions become factual, known truths, making it possible to lay a foundation upon which other ideas may be built. This touches on the principles of relativity, in that our comprehension of the world has developed in successive growth patterns, with every thought, theory, or concept relative to a specific origin. In short, we define the parameters that govern a specific language and employ it to express the qualities of nature.

It is often, if not always true, that the languages of our world overlap, thus creating multiple ways of describing the same concept. It is in this overlap of ideas, where multiple fields strive to understand and explain the same concept, that we are better able to perceive the concept (or the substance of the concept), relate to it, comprehend its significance, and perhaps express it in a new light. Seeing reality through multiple avenues broadens our perception of life, thus manifesting a more unified, holistic, and integrated understanding of the world we live in.

> *"You don't understand anything until you learn it more than one way."* [3]
>
> *~Marvin Minsky*

Concept Fundamentals

Conception is the "act or power of forming notions, ideas, or concepts." [4] It can be seen as the first stage in our attempt to achieve a greater realization of the world. A concept is "the conjunction of all the characteristic features of something, a theoretical construct within some theory, [or] a directly intuited object of thought." [5]

Concepts inspire, dignify, and often justify the significance of a creative product. When concerning architecture that strives to accomplish more than simply house an operation, a design concept is one of most important aspects of the project. An entire phase in architectural design is known as "Conceptual Design," in which the fundamental components of a project are pieced together. The concept formulates the reasoning behind the design's development, and articulates the decisions made throughout the design process. Without a concept – or furthermore, a *strong* concept – the ideas, designs, and creations being presented fall short of provoking a deeper

[3] "Marvin Minsky quotes." ThinkExist.com Quotations. http://thinkexist.com/quotes/marvin_minsky/ (accessed November 22, 2010).

[4] "Conception." Dictionary.com | Free Online Dictionary for English Definitions . http://dictionary.reference.com/browse/ conception (accessed: November 28, 2010).

[5] "Concept." Dictionary.com | Free Online Dictionary for English Definitions . http://dictionary.reference.com/browse/concept (accessed: November 28, 2010).

human reaction. A concept answers the "why" that we so vigorously pry at; it rationalizes the measures that were taken, and brings structure to the creation at hand.

This is not to say that a driving concept behind music, architecture, or any creative expression is essential in justifying its design. Art for art's sake can substantiate its creation, and oftentimes the concept is not even apparent when experiencing the art firsthand. However, knowing what inspired a design unveils a greater depth; we can relate to the material in a different way.

The most challenging task for a creative professional is to bring his/her concept to realization. A strong concept can only stimulate ideas and rationalize their significance; it cannot create the design itself. It is the duty of the creative professional to carry out the concept through his/her design.

Thoughts, Intent, & Inspiration

Robert Bourassa, a well-articulated musician and music theorist, told me, "There is no such thing as music theory. We have laws of music, which are an extension in the study of the laws of physics." A dear friend of mine, Keala Forrest Horwatt – who has studied music for most of his life – told me, "We learn everything there is to know about music theory, but when it comes to actually making music, we forget it all." These statements offer a way in which these two individuals perceive and relate to music. Everything in the world has a natural frequency, a fundamental wavelength. These frequencies guide our perspective through the fabric of existence. We discover things that we like because they harmonize and resonate with our physical being and state of mind.

On a personal level, this research has been an incredibly rewarding experience. When the notion of “musical architecture” first struck my mind, I was instantly intrigued. I knew there were patterns in music, but I could never put a finger on them because I had never learned music theory, or “the laws of music.” To this day, I play music by ear; I allow pure harmonic motion to flow through my fingertips and produce sounds that resonate with my sense of cadence. I have found it quite interesting to walk backwards on the path of music theory to see if what I had produced agreed with the principles of music theory. In some cases, it did; in others, it most definitely did not.

The “overlap theory” is one I had conceived a long time ago, through my own development. I had to relate to a given subject matter in multiple ways before I could really comprehend it; I was never satisfied with accepting anything as simple fact. My ability to flow interchangeably through alternate mediums is what allowed me to conceive the doctrines of this text.

Through my brief experience in musical education, I learned the fundamentals of Western music and witnessed the expressions of music through many other cultures; the patterns I alleged to for so long revealed themselves. I thought it was all downhill from there – got my patterns; good to go! However, I still had no idea why these patterns were so prominent in music. I could not justify anything to myself, let alone an audience, if I did not know the “why” of music philosophy.

This text has been part of my learning process. Through an array of sources, I was able to formulate an understanding of the true principles that dictate musical sounds and musical order. I searched through mathematics and physics, acoustical engineering and social conditioning; I stared into the soul of my guitar for hours on end, beckoning her to tell me how she worked. And sure enough, she spoke with the eloquence of harmonics, and slowly but surely I grasped the concepts that resonate from nature.

The sequential order of my explorations confirms this growth in perception: the initial formations are extremely literal, and the final explorations offer conceptual representations of musical order and relationships. Using Western music theory as a base, I aspired to create methods inherent to the fundamentals of music, thus creating formulas that could be applied to any style, era, or culture. The studies of this thesis offer a runway, from which countless creations can take flight, encouraging further investigation on how music can generate physical form. This text is only the start of a fascinatingly complex theory, for the overlap of music and architecture will sustain a resonance in my mind for the rest of my life.

"The creation of a thousand forests is in one acorn." [6]

~Ralph Waldo Emerson

[6] "Seed Quotes." Joy of Quotes. http://www.joyofquotes.com/seed_quotes.html (accessed December 7, 2012).

Abstract

For the purpose of inspiring innovative methods of creating architectural form, this thesis explores the physical rendering of musical concepts. Precedent study and correlative design research led to three principal modes of translating music into physical form: 1) directly pass soundwaves through an adaptable substance, 2) utilize the techniques or structure of a musical composition, and 3) employ the numerical values found within musical tones and musical relationships. These methods resulted in three primary forms of expression: 1) sound wave formations, 2) physical expressions of the qualities and relationships within musical concepts or "musical ideas," and 3) arrangements of objects in space that communicate and exemplify musical order and structuring. Design explorations correlated musical concepts, musical order, and the numerical values of musical pitches, resulting in literal and conceptual representations of form. The "Melodic Experience," a physical composition representing the proportions between musical pitches and their organization as defined by Western music theory, effectively communicates the primary elements of music by exemplifying rhythm, time, and the rise and fall of pitch through an experiential sequence of physical events. This study is part of the growing methodologies in form-making and contributes to the future development of how music can articulate architectural design.

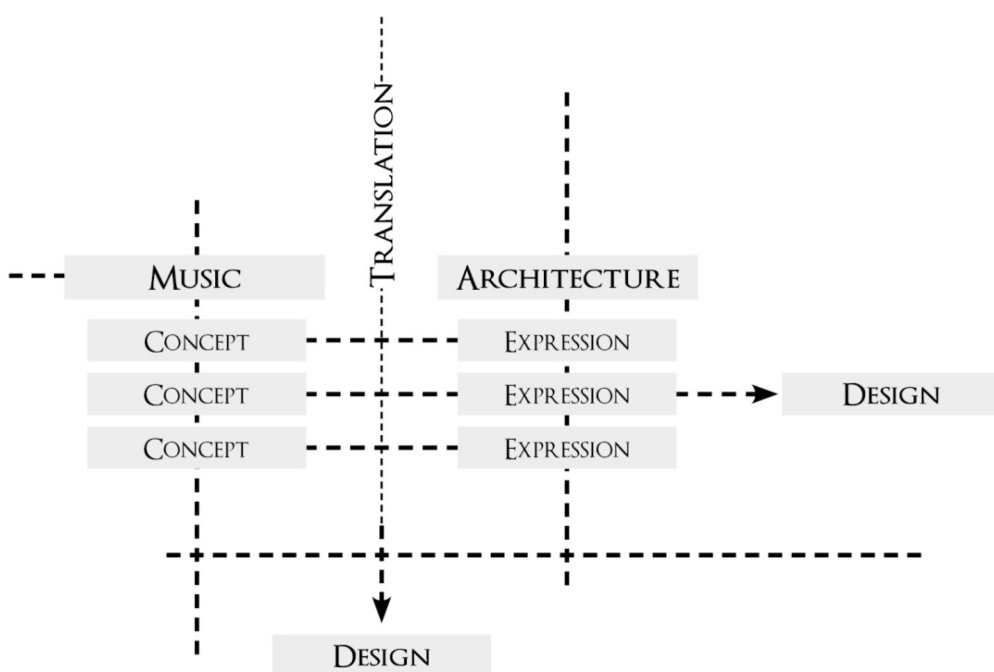
Introduction

Objectives & Methodology

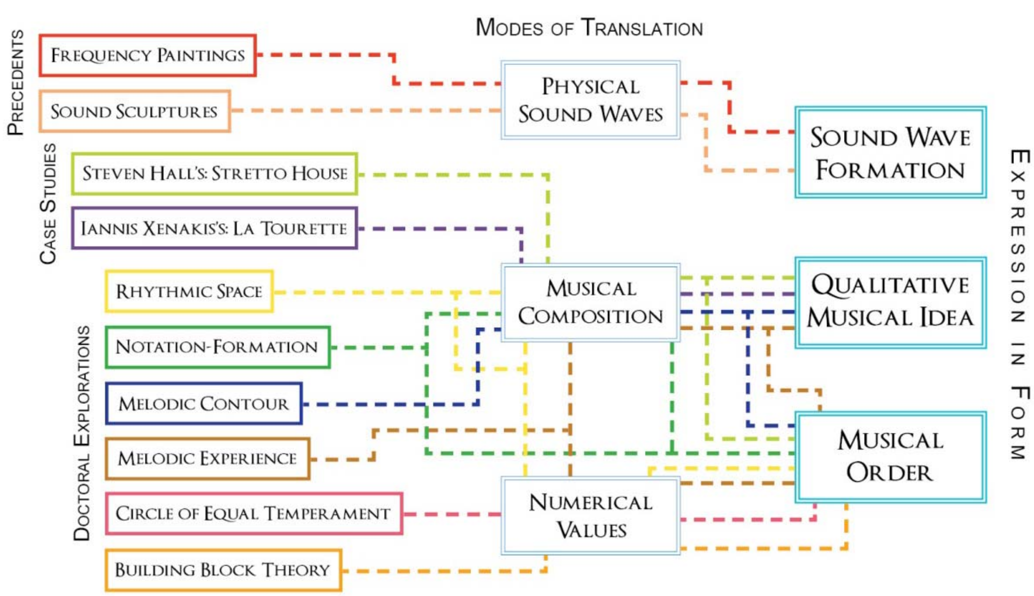
Do music and architecture coincide, or sustain a vicarious relationship? If so, how? Can our physical experience and reaction to music be replicated through our experience and perception of spatial relationships? Can musical notation be directly translated into a physical form? Are the fundamental components and theories that dictate musical order capable of formulating conceptual design? These questions were the founding forces that drove this investigation.

The intent of this thesis was to explore the structure of music and decipher ways musical arrangements could be expressed through three-dimensional forms. The goal of this investigation was to generate possible design methods for architecture, rooted in the design of music. Analysis of the existing knowledge on this subject guided this study's initial discoveries; however, these results grew from what had been achieved in the past into a conceptualization and new definition of "musical form." The laws of music conducted the development of how objects in space can be ordered, and thus perceived in a musical sense. The resulting assemblies are prototypes for ways in which the intangible substance of music may render physical forms.

Correlational research served as the primary methodology used in this investigation. Music and architecture are two separate creative mediums: this thesis devises possible mediators and translation mechanisms that manifest musical concepts through an expression in form. Design explorations correlated musical concepts, musical order, and the numerical values of musical pitches, resulting in both literal and conceptual representations of form. Some explorations break down the formal components of music and merge them with the basic elements that compose a piece of architecture. Other developments evolved from the theories and principles that exist within music, and carried them directly into the arrangement of objects in space. The following figure depicts the overarching process of this investigation. This thesis stands as a translator between music and architecture, where musical concepts are interpreted and represented by an expression in physical form. Further advances to this study may then take a single expression, or the combination of multiple expressions, and articulate an architectural design.



The existing knowledge delineating the relationships between music and architecture can be organized into five primary categories: the educational theory of the two fields, their structure and composition, the science of Cymatics, design methods of musically inspired artists and architects, and precedents that present the parallels between the two practices. Analysis of these categories, combined with correlative design research, led to three principal modes of translating music into physical form: 1) directly pass soundwaves through an adaptable substance, 2) utilize the techniques or structure of a musical composition, and 3) employ the numerical values found within musical tones and musical relationships. These methods resulted in three primary forms of expression: 1) sound wave formations, 2) physical expressions of the qualities and relationships within musical concepts or "musical ideas," and 3) arrangements of objects in space that communicate and exemplify musical order and structuring. The following diagram depicts this analysis.



Music theory can be defined as the thoughts and studies that analyze the way in which music is formulated. It examines music and the notation that expresses it as a language, identifying patterns and principles that govern the techniques utilized to compose music.[7] Overall, music theory analyzes and describes the elements of music. According to Benjamin Boretz's *Meta-variations: Studies in the Foundations of Musical Thought*, the primary elements of music are rhythm, harmony, melody, structure, form, and texture.[8]

Examining music theory unveiled the patterns and principles of music, and constructed this investigation's fundamental foundation – a base for the assembly and composition of "musical form." Because this investigation utilizes the way in which music is structured, it must first be realized that there are infinite approaches to musical composition, primarily due to the vast cultural understanding of musical order. As such, this thesis predominantly focused on the primary principles and elements of music as defined by Western music theory.

The fundamental definition of music is that of organized sound, or "the art of arranging sounds in time so as to produce a continuous, unified, and evocative

[7] Gary C. White, David Stuart, and Elyn Aviva. *Music in Our World: An Active-Listening Approach*. Boston: McGraw Hill, 2001; Gary C. White. *Music first!*. 5th ed. Boston: McGraw-Hill, 2007; George Thaddeus Jones. *Music Theory* . New York: Barnes & Noble Books, 1974; "What Is Music Theory?" Dummies.com; Making Everything Easier . http://www.dummies.com/how-to/content/what-is-music-theory.html (accessed April 20, 2011).

[8] Boretz, Benjamin, *Meta-variations: Studies in the Foundations of Musical Thought* (New York: Open Space, 1995).

composition."[9] The above notion of sound speaks specifically to the musical elements of pitch, melody, harmony, and timbre. The aspect of organization communicates the convention of musical structure, primarily expressed through musical rhythm. The procession of musical events, as organized by rhythm, defines music as a progressive function of time.

A further refinement of this interpretive definition of music can reduce the primary elements of music to rhythm, time, and a rise and fall in pitch. The definition of music, these primary elements, and the doctrines of Western music theory were used in combination to analyze the investigations presented in this text, evaluating their effectiveness in communicating and expressing music through three-dimensional form. It was thus determined that the "Melodic Experience" successfully translated our aural perception of music to our visual perception of space.

[9] "music." Dictionary, Encyclopedia and Thesaurus - The Free Dictionary. http://www.thefreedictionary.com/music (accessed October 14, 2012).

Thesis Body

A Melodic Experience

The "Melodic Experience," a physical composition representing the proportions between musical pitches and their organization as defined by Western music theory, effectively communicates the primary elements of music by exemplifying rhythm, time, and the rise and fall of pitch through an experiential sequence of physical events.

This exploration was inspired by the technical use of a melodic contour as a means of visually representing the rise and fall of pitch in a given melody. The melodic contour was adjusted to adequately represent the specific change in frequency and the duration of each musical pitch in alignment with the song's tempo and the average human walking speed. The adjusted contour was then revolved to create a walkable corridor, where the undulating surface of the form stood as a direct representation of the melody's fundamental components. The human perception of the intangible auditory devices of music were correlated to our visual perception of space. The primary correlation is our reaction to the aural proportions between sounds over time and the visual proportions of space and matter through time.

The image to the right depicts how the musical elements of frequency and duration are applied to the construction of the "Melodic Experience." This formula furnishes the user's perceptual experience by expressively evoking the similar tension-release patterns induced through the physics of sound, as articulated by a musical composition.

This study was initially tested on my original composition, “A Sunny Winter Day.” Music notation served as the mediator between our auditory perception of the musical composition and the formation of the “Melodic Experience.” The following image is the initial score of “A Sunny Winter Day,” depicting the melodic contour drawn over the primary melody of the song:

This song is written in F major, with a 4/4 time signature. The primary melody, written on the treble clef, is played in an *allegro* fashion at 120 beats per minute (BPM). The melodic contour was then adjusted to adequately represent the change in frequency and the duration of each musical pitch. Frequency interval proportions were used to adjust the vertical orientation of each point on the melodic contour. A horizontal line from each point was drawn with a length that corresponded the duration of each pitch to a person’s average walking speed. Based on a Portland University study of pedestrian walking speeds, the rate of 4 feet per second was selected as a person's average walking speed.[10] A 4/4 time signature dictates that there are four beats per measure, with a quarter note receiving each beat. At a tempo of 120 BPM, each quarter note would sound for half a second. In alignment with an average walking speed of 4-ft/s, each quarter note receives a 2-ft. leaner segment (horizontal length on melodic contour). The diagrams below depict the numerical analysis of the melody, showing the calculations for frequency intervals, the formula for the beat's durational length, and the adequately adjusted melodic contour.

DURATION (SEC) : .25 .25 .25 .25 1 .25 .25 .5 1 .25 .25 .25 .25 .5 .5 .5 .5 1

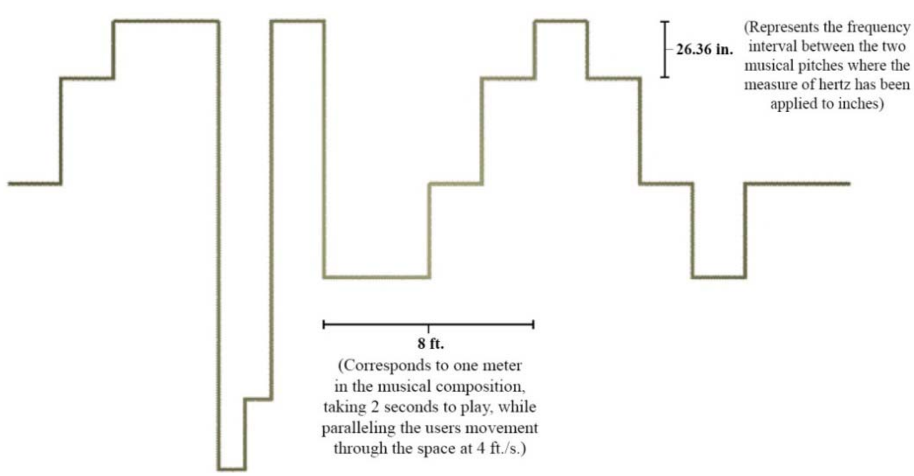
FREQUENCY (HZ) : 392 392 440 440 466.16 261.63 293.66 466.16 349.23 392 392 440 440 466.16 440 392 349.23 392

NOTES : G - G - A - A - B^b - C - D - B^b - F - G - G - A - A - B^b - A - G - F - G

RELATIVE INTERVAL (HZ) : 0 +48 0 +26.16 -204.53 +32.03 +172.5 -116.93 +42.77 0 +48 0 +26.16 -26.16 -48 -42.77 +42.77

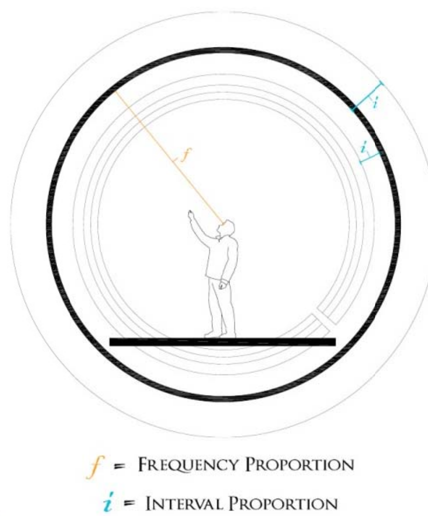
$$\text{BEAT'S DURATIONAL LENGTH (ft./beat)} = \frac{\text{AVERAGE WALKING SPEED (4 ft./sec.)}}{\text{TEMPO (BPM) / 60 (sec./min.)}}$$

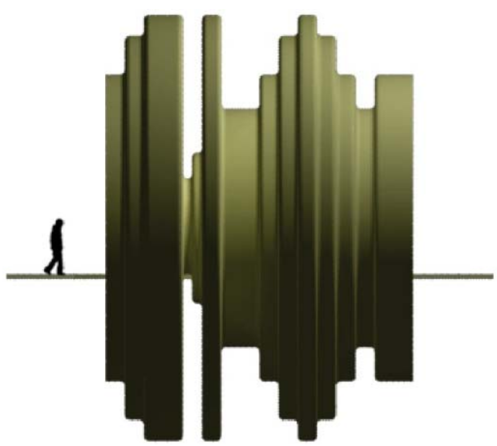
ADJUSTED MELODIC CONTOUR



[10] Nick Carey and Karen Aspelin. "Draft Results: Establishing Pedestrian Walking Speeds," Portland State University (May 31, 2005). http://www.westernite.org/datacollectionfund/2005/psu_ped_summary.pdf (accessed April 24, 2011).

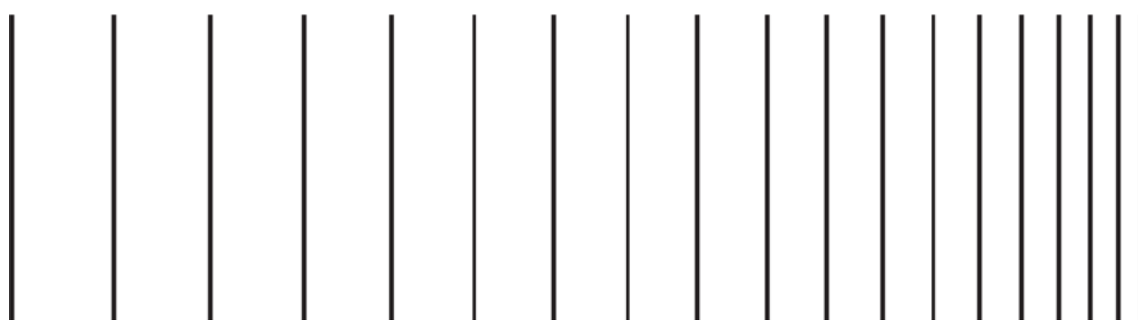
Once the melodic contour is adequately adjusted, it can then be used to create a three-dimensional form. To align our visual perception of the form with our auditory perception of the melody, the melodic contour was revolved around a horizontal axis to create a circular form, where the distance from the axis of revolution to the form's inner surface is equal in all directions. A walkable base plane was strategically inserted to align an average person's eye level with the axis of revolution. Considering both men and women, an average eyelevel is approximately 5'-4" high; for measurements that are more precise, please refer to the text *Architectural Graphic Standard*.





The visual experience of walking through this corridor parallels the auditory experience of listening to the songs predominant melody. The proportions between the surfaces of the form, the distance from eye level to the inner shell, the length between the form's undulation, and the rate at which a person experiences these changes in proportion all precisely reflect the perception of listening to the melody of "A Sunny Summer Day."

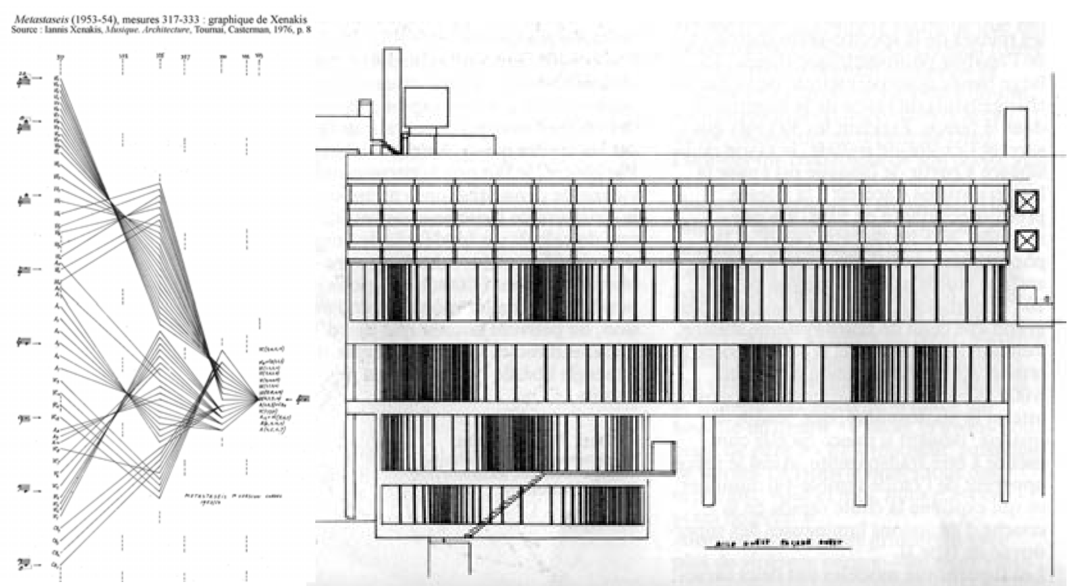
The "Melodic Experience" was then analyzed to verify how effectively it communicated the primary elements of music: rhythm, time, and change in pitch. Our primary physical response to music is subject to audible rhythms. We act upon these rhythms by physically moving to the beats.[11] Our minds are also perceptive to *visual* rhythms, giving them the potential to evoke similar physical responses. As your eyes move across the set of lines below, a visual rhythm is established by the change in line spacing, and will tend to speed up as you move your eyes from left to right.



World-class engineer, mathematician, architect, and composer Iannis Xenakis excelled in all four of these esteemed professions, pushing the boundaries between

[11] Gary C. White, David Stuart, and Elyn Aviva. "Our Response to Music." *In Music in Our World: An Active-Listening Approach*. Boston: McGraw Hill, 2001.

them. Xenakis moved between disciplines and increased his overall perception and expression by using each to critique the other. Working hand-in-hand with the world-renowned architect Le Corbusier, Xenakis applied the musical rhythm used in his composition “Metastaseis” (1953-1954) to the visual rhythm created by the “Undulating Glass Panes” of their architectural endeavor, Sainte Marie de La Tourette (1953-1960). While designing the compositions of “Metastaseis” and La Tourette, Xenakis was inspired by the techniques of glissandi (the rapid sliding up or down of the musical scale), chiaroscuros (the use of light and dark elements in a pictorial work), and the criterion of density in the number of events per unit of time.[12] The images below depict Xenakis’s graphic representation of the last section in “Metastaseis” and the West elevation of La Tourette.

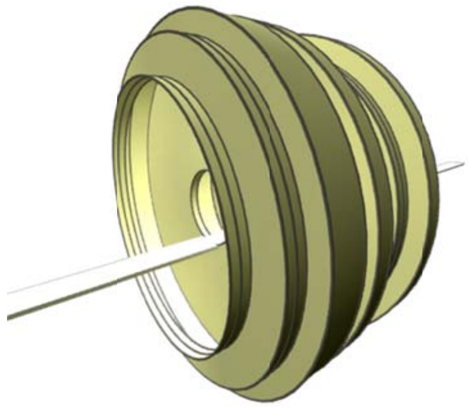


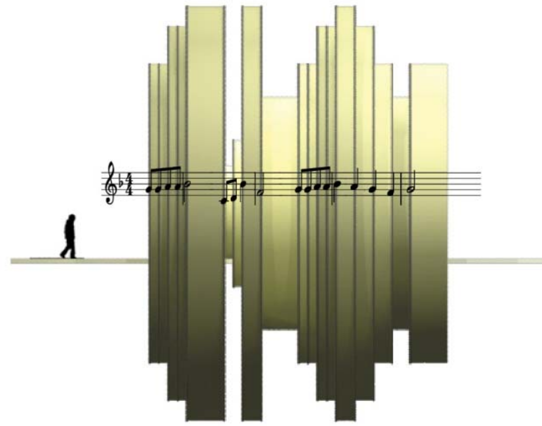
[13]

[12] Xenakis, Iannis, and Sharon E. Kanach. "The Le Corbusier Years." In *Music and architecture: architectural projects, texts, and realizations*. Hillsdale, NY: Pendragon Press, 2008. 41-47.
[13] "Xenakis as Architect." Iannis Xenakis. http://www.iannis-xenakis.org/xen/archi/real.html (accessed November 5, 2012).

A stringed instrument can play five notes every second. In "Metastaseis," Xenakis implemented the use of 62 different string instruments, each sounding the intervals of the 12-tone chromatic scale in durations proportional to the relationship of each pitch. The graphic representation of "Metastaseis" expresses the movement of each instrument by a diagonal line, where the ascending and descending structures represent a rise and fall in pitch. The vertical dashed lines highlight the areas of convergence (density) and separation (openness) between the pitches of each instrument. The durations are based on an additive mathematical progression of stochastic calculations. This same technique was applied to the mullion spacing of La Tourette's fenestration, where the audible density of pitch has been applied to the visual density of window frames. This resulted in an intense display of varying rhythm across the horizontal façade of each floor. Vertically, Xenakis expressed the musical concept of harmonic counterpoint through the variable densities between each floor.

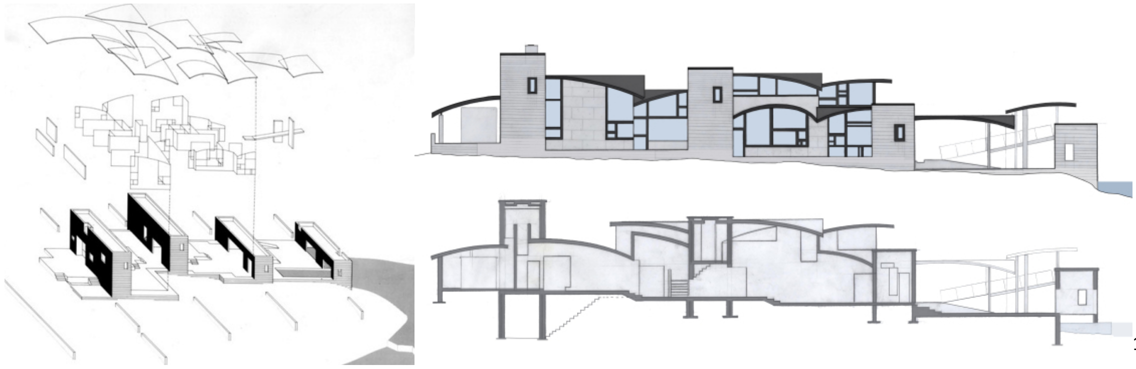
The "Melodic Experience" expresses musical rhythm both visually and experientially. We see the rhythm of the melody expressed by the expansion and contraction of the form, heightened by experiencing the rhythm through a shift in spatial density. To enhance the musical rhythm of the form, a circular rib was added at every point a musical note would be struck. The images on the following page illustrate the musical rhythm of the "Melodic Experience."





Johann Wolfgang von Goethe said, “I call architecture frozen music.”[14] Architecture can be viewed as a fixed object; however, it creates an atmosphere that is experienced through time. The Stretto House (1989 - 1991), designed by Steven Holl, stands as a powerful example of a musical concept frozen in time. Sited in Dallas, Texas, adjacent to a river flowing into three dammed ponds, the house is a delicately composed a piece of architecture that reflects the site’s contextual qualities while physically representing characteristics found within Béla Bartók’s musical composition “Music for Strings, Percussion and Celestra.” Holl was particularly inspired by Bartók’s use of the musical concept of *stretto*, “the close overlapping of two parts or voices, the second one entering before the first has completed its statement of the subject.”[15]

[14] "Johann Wolfgang von Goethe Quotes." Notable Quotes. http://www.notable-quotes.com/g/goethe_quotes.html (accessed December 7, 2012).
[15] "Stretto | Define Stretto at Dictionary.com." Dictionary.com. http://dictionary.reference.com/browse/stretto (accessed March 21, 2011).

 [16]

The house is divided into four parts, reminiscent of the four distinct musical sections of Bartók's composition. The dividers take form as solid concrete blocks, creating "spatial dams" between the overlapping flow of "aqueous space" throughout the house. The roof forms are curvilinear, and overlap each other as well as parts of the concrete blocks. "Music for Strings, Percussion and Celestra," is composed entirely of percussion and stringed instruments creating a contrast between heavy and light elements. Holl expressed this relationship through the contrast of lightly-framed glass walls with the solidity of the roof forms and concrete masses, while simultaneously opposing curved roof forms with rectilinear walls.[17]

[16] "STRETTO HOUSE." STEVEN HOLL ARCHITECTS. http://www.stevenholl.com/project-detail.php?id=26&worldmap=true (accessed March 21, 2011).
[17] "STRETTO HOUSE." STEVEN HOLL ARCHITECTS. http://www.stevenholl.com/project-detail.php?id=26&worldmap=true (accessed March 21, 2011); Martin, Elizabeth. "Layered Relationships." In *Architecture as a translation of music*. New York: Princeton Architectural Press, 1994. 56-59.

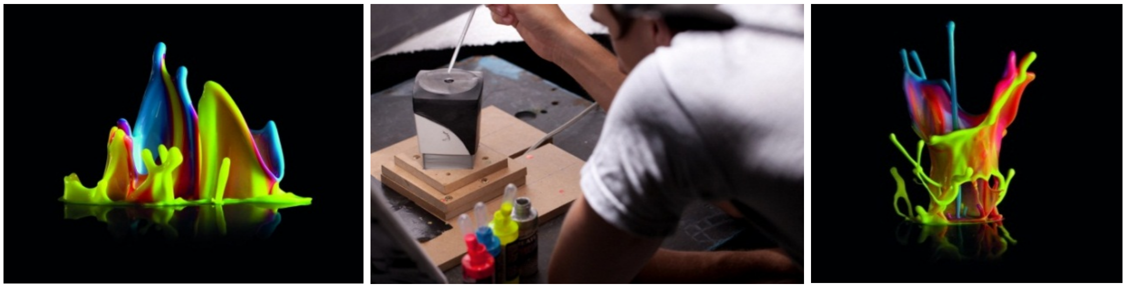
18

La Tourette, the Stretto House, and the “Melodic Experience” all portray musical elements through visual stimulus. They can be viewed as static objects and yet also experienced by our movement through space. Xenakis applied his musical rhythm to a two-dimensional solution, where the Stretto House and the “Melodic Experience” create spatial atmospheres that reflect particular qualities of music. In all cases, a physical movement of the eye and/or body captures the element of time.

In the fall of 2010, the creative studio Detsu collaborated with biochemist/photographer Linden Glendhill, launching a project called “Bringing Colour to Life.” The project captured the forms created when sound is passed through a liquid. Latex was stretched over a small speaker and a few drops of paint were placed in the center of the membrane. For a fraction of a second, the vibrations of a single tone

[18] "STRETTO HOUSE." STEVEN HOLL ARCHITECTS. http://www.stevenholl.com/project-detail.php?id=26&worldmap=true (accessed March 21, 2011).

caused the paint to jump into spectacular sculptures, while high-definition cameras on a revolving platform photographed the ephemeral life of the paint's physical form.[19]


[20]

Similar "sound sculptures" have been created by passing various frequencies through non-Newtonian fluids. These forms embody a single musical tone or the combination of multiple musical tones; however, they are more of an expression of the physical qualities of vibration than they are a representation of music.

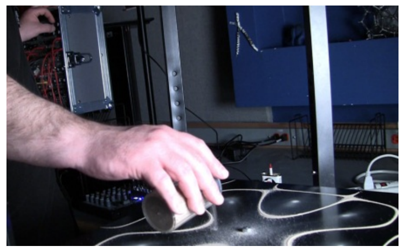

[21]

Through research conducted at the Banff Center from 2009-2011, artist Gary James Joynes utilized Hanz Jenny's cymatic principles, and a technique invented by Ernst Chladni, to produce over 140 "frequency paintings" generated by passing pure tone frequencies through particulate sand on Chladni Plates. Joynes selected twelve forms to

---

[19] Delana. "Paint + Sound = Sculpture?." WebUrbanist . http://weburbanist.com/2011/05/11/paint-sound-sculpture-wild-photos-videos-included/ (accessed October 7, 2012).
[20] DB, Nate. "dentsu: paint sound sculptures." designboom. http://www.designboom.com/weblog/cat/10/view/11774/dentsu-paint-sound-sculptures.html (accessed October 7, 2012).
[21] UltraSloMo. "Creature in the Sonic Liquid." YouTube. http://www.youtube.com/watch?v=Yw4qklgNIxI (accessed October 7, 2012).

display in the *12 Tones* installation of his *Frequency Paintings* series, where each display emits the tone that generated its design. A sensor installed at each piece triggers a random alteration in the volume of each pure tone, creating an ever-changing soundscape of auditory experience.[22]

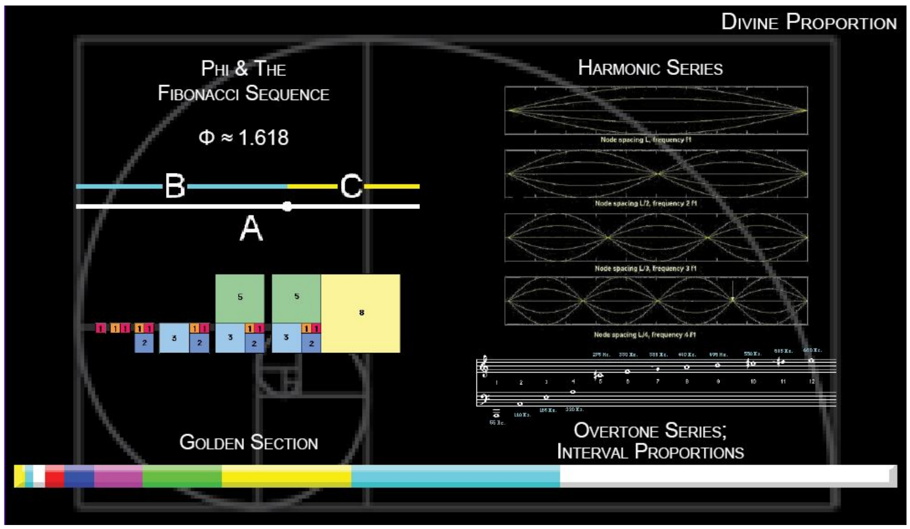
[23]

The “Melodic Experience” could be enhanced in a similar fashion by hardwiring the form with sensors and speakers at each physical representation of the song’s melody. This would allow a person to experience the audible and spatial shift of the melody simultaneously, and directly link his/her visual perception with our auditory senses.

Frequency vibrations through Chladni plates move the particulate sand into the areas of no vibration, highlighting the nodal lines of the frequency’s wavelength. A purely natural phenomenon creates the proportions of these forms, thus exemplifying the metaphysical order of nature. Helen Gardner and Fred Kleiner, in *Gardner’s Art Through the Ages*, state that, “To the Greek mind, proportion in architecture and

[22] Joynes, Gary James. "12 TONES « GARY JAMES JOYNES | FREQUENCY PAINTING SERIES." The Website of Artist Gary James Joynes. http://www.clinkersound.com/frequency-painting/?page_id=66 (accessed October 7, 2012); Candler, David. "FREQUENCY PAINTING: 12 TONES." The Website of Artist Gary James Joynes. http://www.clinkersound.com/frequency-painting/?page_id=365 (accessed October 7, 2012).
[23] Joynes, Gary James. "12 TONES « GARY JAMES JOYNES | FREQUENCY PAINTING SERIES." The Website of Artist Gary James Joynes. http://www.clinkersound.com/frequency-painting/?page_id=66 (accessed October 7, 2012)

sculpture was much the same as harmony in music, reflecting and embodying the cosmic order."24 Analogous proportions were utilized in Roman temples, Gothic cathedrals, Renaissance revival architecture, Tibetan mandalas, Buddhist stupas, meditation paths, figures of the Chinese *I Ching*, and ancient architecture of many other cultures and civilizations across the globe.[25]



This ideal of "divine" proportion and cosmic order has shaped architecture by the use of the golden section and music through the overtone series; one applies to our perception of visual proportion, the other to aural proportion. The golden ratio arose from the Fibonacci sequence where the overtone series arose from the harmonic series (natural divisions of a vibrating string producing the interval proportions of just intonation, or the overtone series). The use of these natural proportions and divine

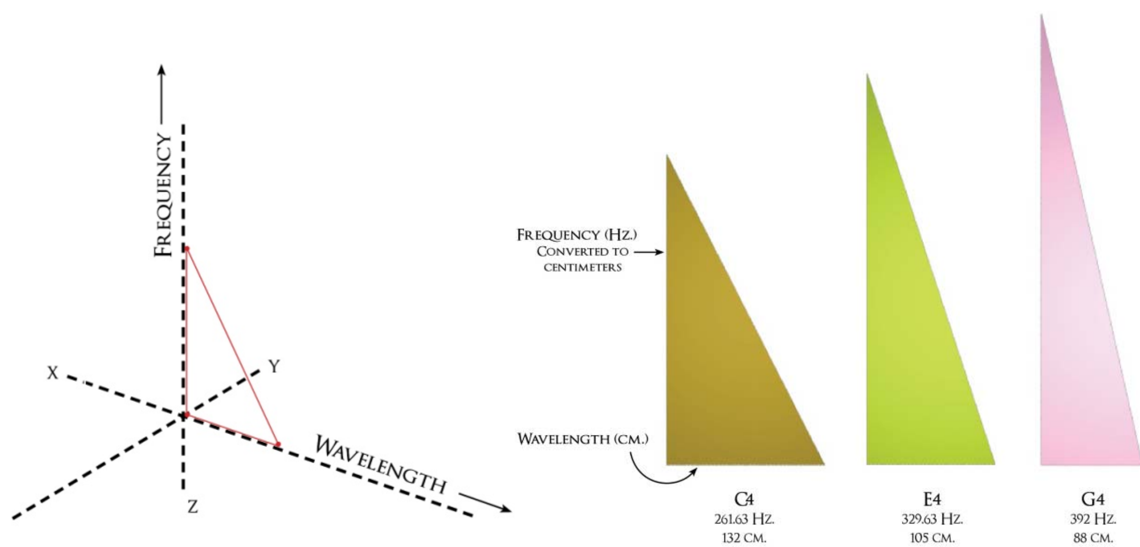
---

[24] Gardner, Helen, and Fred S. Kleiner. *Gardner's Art Through the Ages: The Western Perspective*. 13th ed., Student ed. Boston, Mass.: Wadsworth Cengage Learning, 2010.

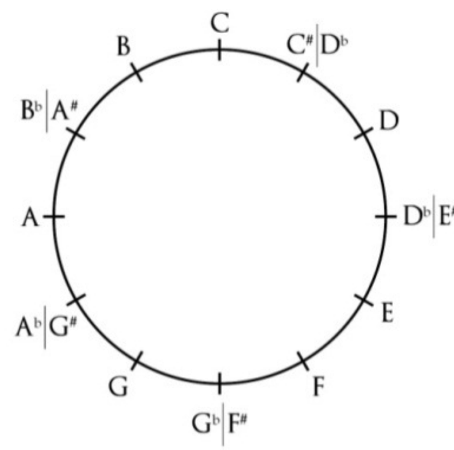
[25] Smith, Greg J.. "Frequency Painting - Gary James Joynes Interview." Vague Terrain | Digital Art / Culture / Technology. http://vagueterrain.net/content/2011/01/frequency-painting-gary-james-joynes-interview (accessed October 7, 2012).

order within the fields of music and architecture draws a strong comparison between the two progressive mediums; however, it does not define architecture as a physical representation of music. Applying the actual proportions between musical sounds to the proportions of objects in space would create a far more significant link between the two fields.

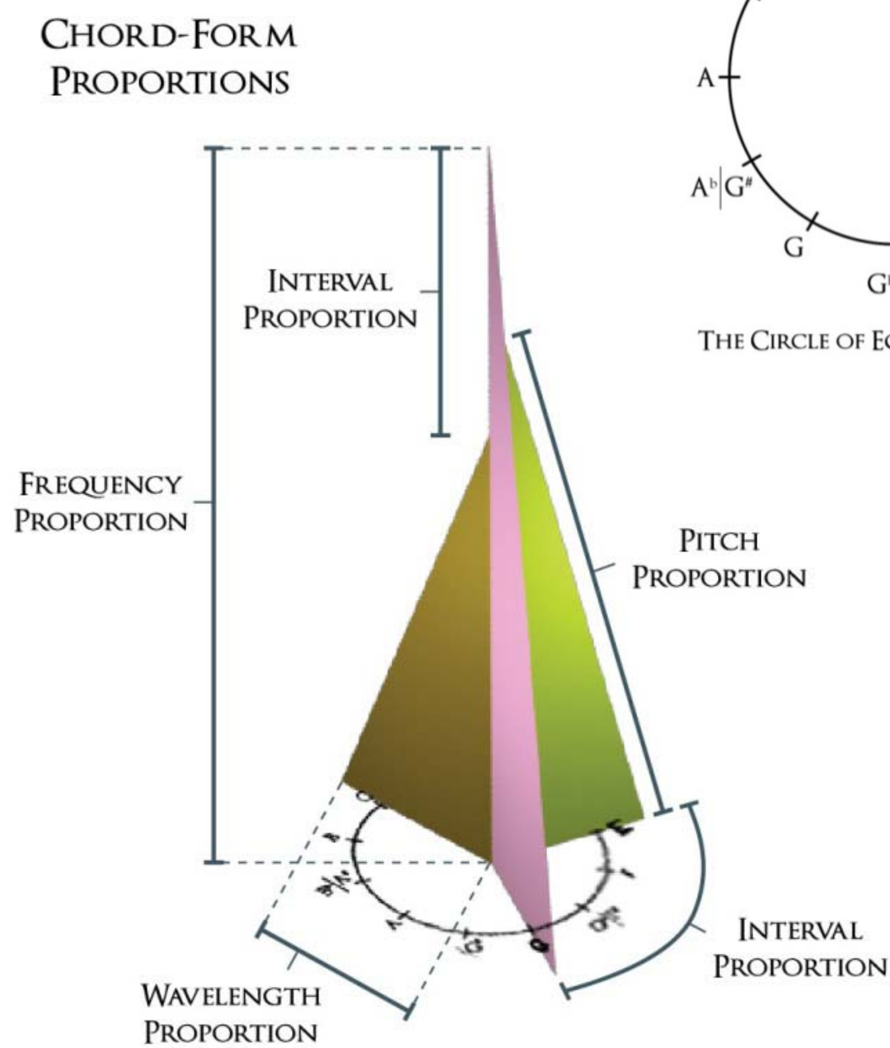
The “Building-Block Theory” exploration of this thesis created forms defined entirely by proportions of musical pitches and their interval relationships. The frequency and wavelength of each pitch were plotted on a separate Cartesian axis. The points were then connected to form triangular “Shape-Notes,” where each segment of the shape stands as a proportional representation of the musical pitch (see below).

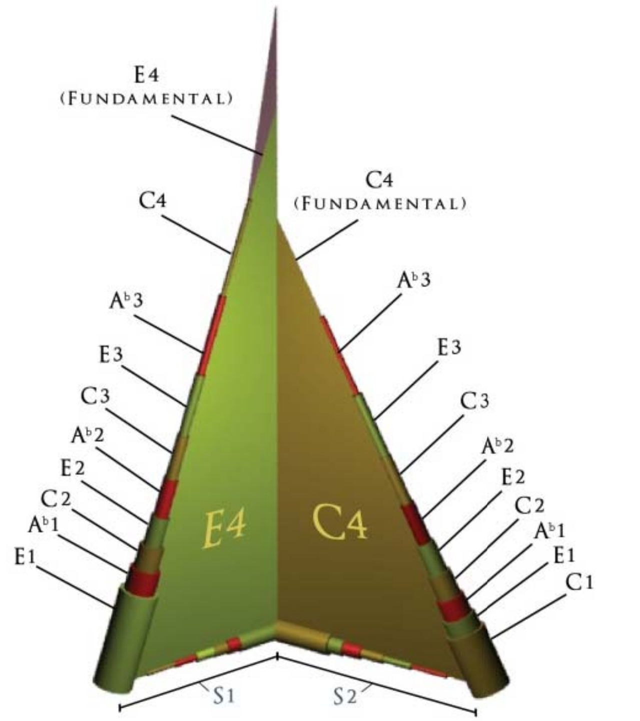


A convention titled “The Circle of Equal Temperament,” was created to represent the twelve equally spaced intervals of Western music by dividing a circle into twelve equal segments, where each node represents a note of the Western chromatic scale. The notion that the device comes full circle, back to the tonic, also conveys our perception of the octave as the same sound. “The Circle of Equal Temperament” was used as an organizational element to arrange the Shape-Notes in a manner that conveyed the interval relationships between the pitches of a musical chord, and resulted in a three-dimensional form (a “Chord-Form”). The images below illustrate “The Circle of Equal Temperament,” its constructive use to create a “Chord-Form,” and the proportions that each “Chord-Form” expresses.



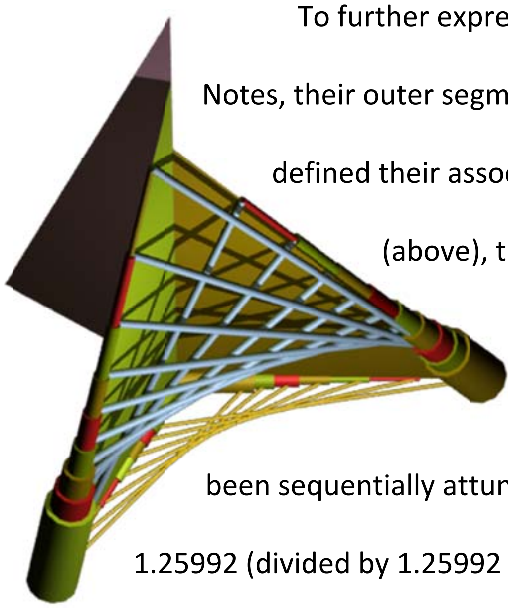
THE CIRCLE OF EQUAL TEMPERAMENT





RELATIVE
INTERVAL DIVISIONS

S1 IS TO E4 · AS · S2 IS TO C4
THIS RELATIONSHIP STANDS TRUE BETWEEN ALL CORRESPONDING INTERVALS AND THEIR FUNDAMENTAL SEGMENTS



To further express the interval relationship between the Shape-Notes, their outer segments were divided by the interval ratio that defined their association. In the *Relative Interval Divisions* diagram (above), the interval relationship between the two Shape-Notes is a major third; consequently, the fundamental lengths of the segments have been sequentially attuned by the equal temperament ratio of 1 : 1.25992 (divided by 1.25992 in a **sequence**). These segments were then connected in various ways that articulated relationships between the musical pitches.

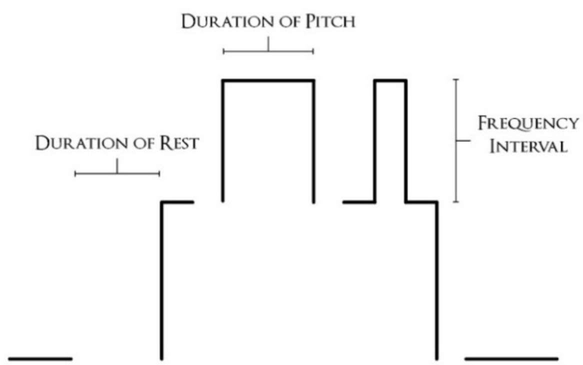
The Chord-Forms of the Building-Block Theory render a multitude of musical concepts in physical form, primarily using proportion and numerical values of musical sounds as a generator. These forms are much like that of the sound sculptures, in that they are literally a physical representation of sound frozen in time. They fall short in truly representing music, however, because they lack an expression of duration as a sequential change of events over time.

After analysis determined the "Melodic Experience" as an effective translator of the primary elements of music, its method of form-making was tested using several musical compositions to evaluate its efficacy. Three alternate songs were specifically chosen for their variations in tempo, rhythm, and melody. The songs selected were "TNT" by AC/DC, "Let It Be" by The Beatles, and "B.Y.O.B." by System of a Down. During the construction of each song's "Melodic Experience," minor adjustments were made to accommodate specific qualities of the song. The "Melodic Experience" method of form-making was not altered; it was only enhanced to adopt the qualities of musical rests and harmony.

The song "TNT," by AC/DC, implements the use of rests between select musical pitches of the primary melodic line. The form of the "Melodic Experience" adapted to this technique by leaving gaps in the form, correlative to where musical rests take place in the melody. These breaks in the form are proportional to the duration of each musical rest, and were calculated using the invented formula for a "beat's durational length." The song is played at a tempo of 125 BPM, giving each beat a linear extrusion of 1.92 ft.

The following diagrams depict the process of construction and the resulting form of AC/DC's "TNT."

AC/DC - TNT · Primary Melodic Line

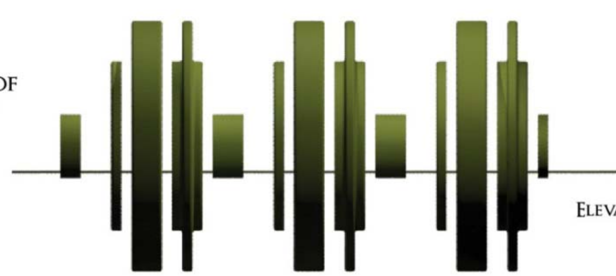


Melodic Contour Adjusted to Represent
Frequency Proportion
& Beat's Durational Length

Perspective View

Entry View

Melodic Experience of
the 1st 3 Phrases in
AC/DC's · TNT



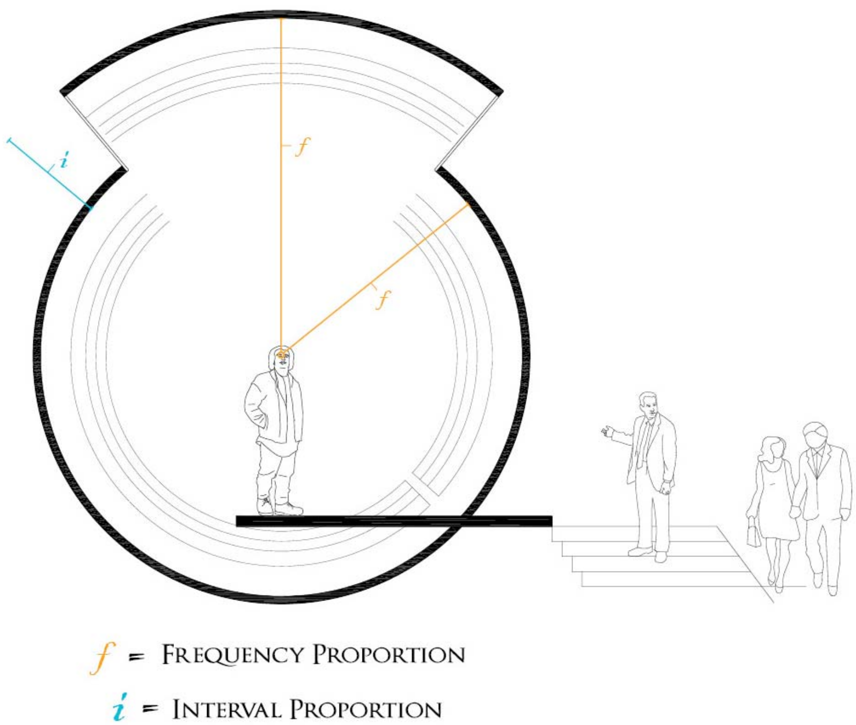
Elevation

The primary melodic line of the song “Let It Be” by The Beatles, is a vocal melody. This melody is backed by a chord progression known as an accompaniment, introducing the element of harmony, multiple pitches sound simultaneously. The image below is the opening score of “Let It Be,” where the vocal melody and accompaniment are pointed out. The “Melodic Experience” adopted this element by creating two separate forms (one for the primary melody and one for the accompaniment) and combining them, where the accompaniment created the base of the form and the vocal melody created the top.

[26]

26 Lennon, John, and Paul McCartney. "Let It Be." *Online Sheet Music*. Sony/ATV Music Publishing, n.d. Web. 6 Oct. 2012. <http://www.onlinesheetmusic.com/let-it-be-p361927.aspx>.

The diagram below depicts how our visual perception of the "Melodic Experience" is now reacting to two separate entities, representing a textural element of the song, and creating an experience that parallels our "polyphonic" perception of music.



When multiple pitches sound simultaneously, the human ear perceives the pitch as an average of the sound's frequencies, yet the mind is able to distinguish the melody and the accompaniment as two separate entities.[27] Therefore, the frequencies of the pitches comprising the chords of the accompaniment were averaged to get a single numerical value for the radius of the base form. Because this song incorporates

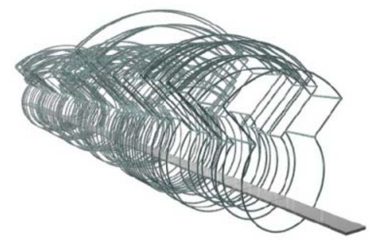
---

[27] Feilding, Charles. "Lecture 012 Hearing VII." College of Santa Fe Auditory Theory. http://www.feilding.net/sfuad/musi3012-01/html/lectures/012_hearing_VII.htm (accessed October 1, 2012); Deutsch, Diana. "Hearing music in ensembles." *Physics Today*, February 2010.#

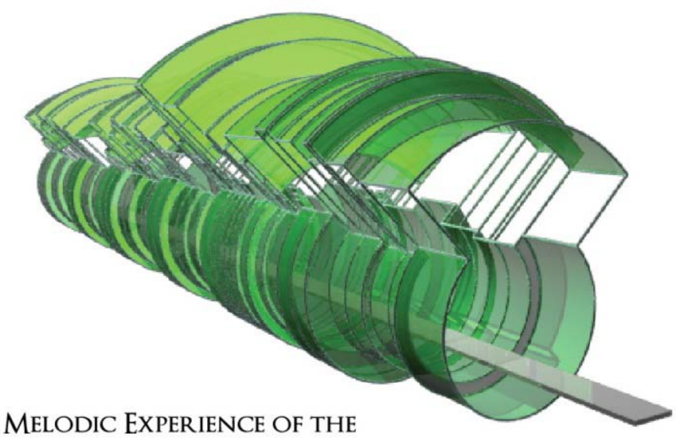
successive notes of the same pitch, a structural framing was integrated with the form to highlight the rhythmic nature of the song. “Let It Be” is played at a tempo of 70 BPM, giving each beat a durational length of 3.43 feet, making each quarter note almost twice as long as those found in AC/DC’s “TNT.” The images below represent the combination of elements that formed the Melodic Experience of “Let It Be.”

Vocal Melody

Accompaniment



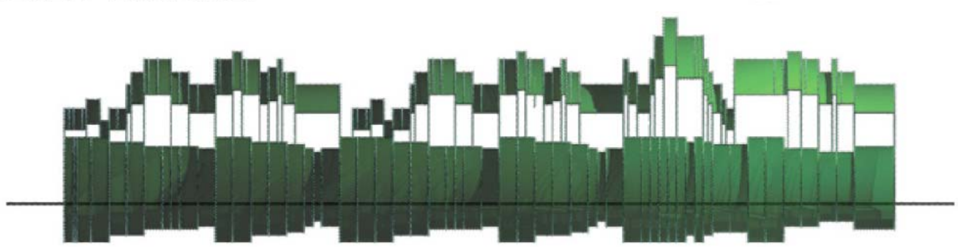
Rhythmic Framing



Perspective View

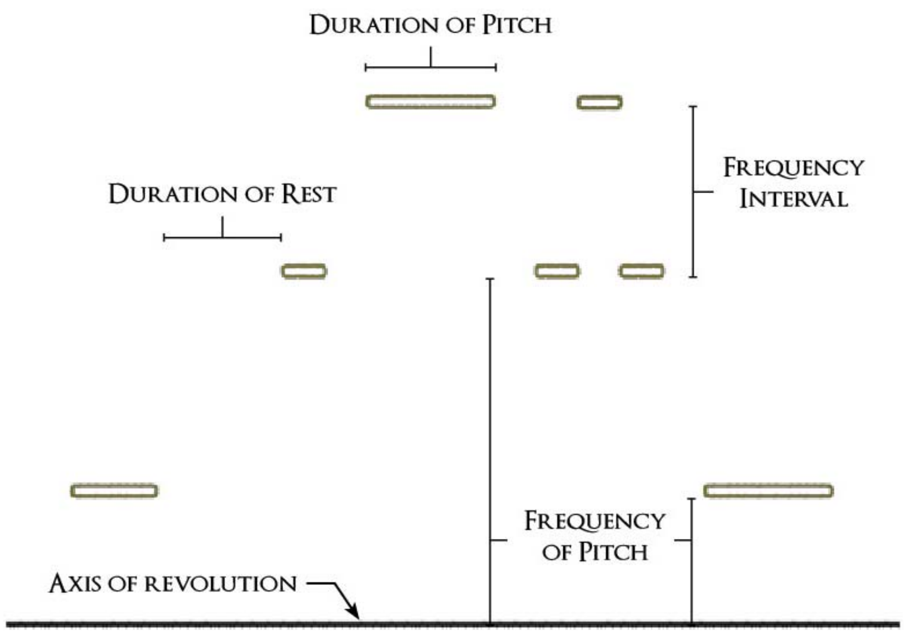
Entry View

Melodic Experience of the First & Second Verses, and the Chorus in “Let It Be,” by The Beatles

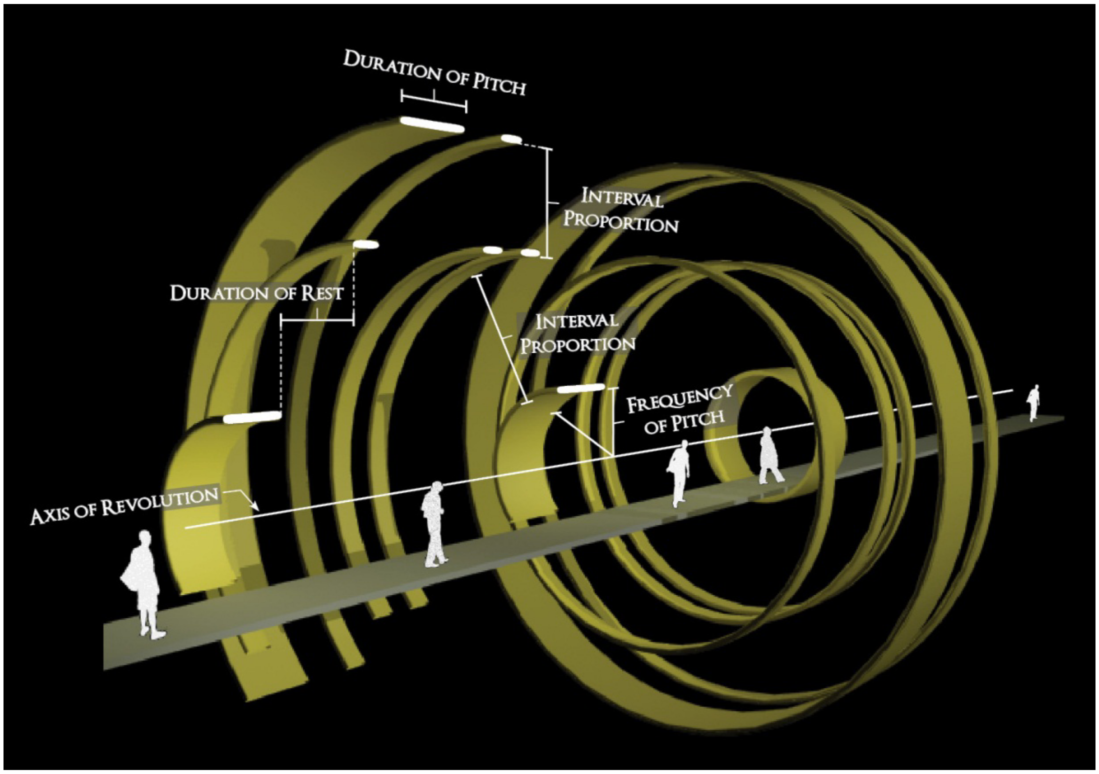


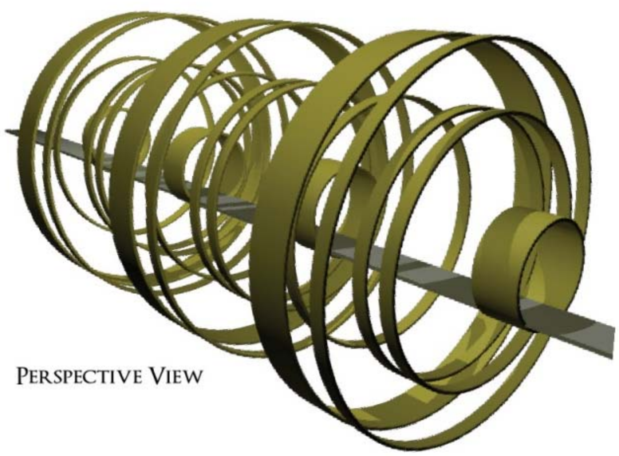
Elevation

A refinement was then tested on the melodic contour of AC/DC's "TNT," removing the vertical lines, so that the only physical elements left were those that represented the pitches of the melody. The horizontal lines were then replaced with 3-inch linear segments, where there length and relationship to one another embodied the melody's most essential elements: pitch duration, rest duration, frequency intervals, and pitch frequency from the axis of revolution at eye level. This catered to the user's overall experience by strictly linking the visual perception of the form to the auditory perception of the melody. The diagrams below depict this adjustment to the melodic contour and illustrate the overall perception of the form.



LINEAR SEGMENTS OF MELODIC CONTOUR

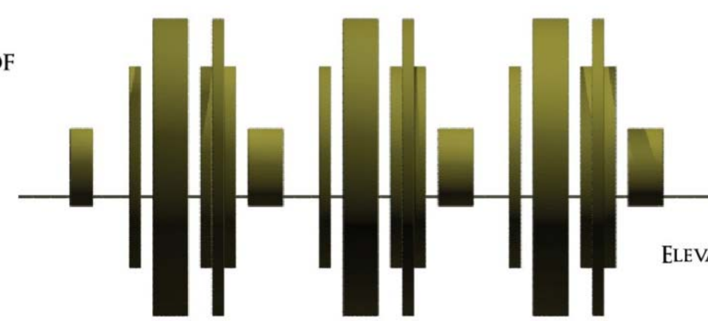




Perspective View

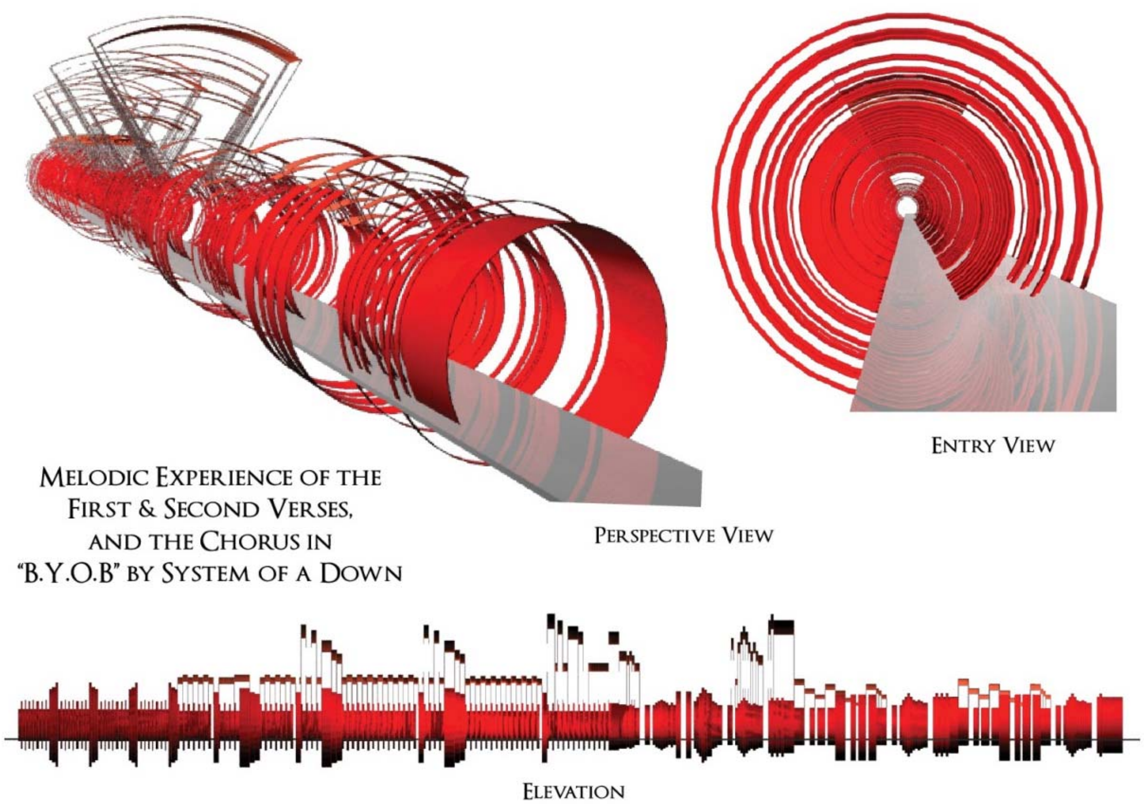
Entry View

Melodic Experience of
the 1st 3 Phrases in
AC/DC's · TNT



Elevation

The next song analyzed was "B.Y.O.B." by System of a Down. "B.Y.O.B." presents an intense rhythmic progression, played at an allegrissimo tempo of 160 BPM, while offering a wide variety of musical transitions. Like "Let It Be," "B.Y.O.B." relies heavily on the vocal melody to communicate its primary melodic structure; subsequently, this song's Melodic Experience was constructed with an accompaniment as its base and the vocal melody as the upper portion of the form. In areas where the vocal melody drops out, the accompaniment takes over to create the whole form. The images below portray the Melodic Experience of System of a Down's "B.Y.O.B."



Melodic Experience of the First & Second Verses, and the Chorus in "B.Y.O.B" by System of a Down

Concluding Thoughts

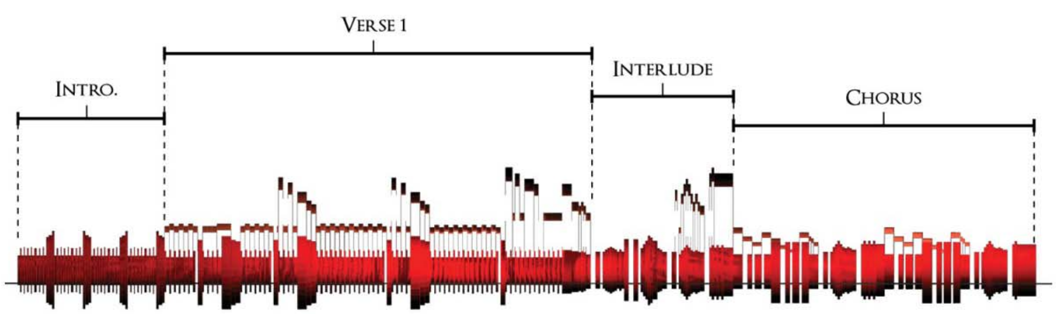
The Melodic Experience represents the proportion of pitch frequency in the distance from the center of revolution to the inner shell of the form. A change in this proportion takes place in forward motion, aligning the flux of pitch frequency with the duration of each pitch in a melody or a song. This combination of change in proportion over time is what establishes the “Melodic Experience” as

an effective translator of the primary elements of music: rhythm, time, and melody. Our audible perception and experience of music’s primary elements have been directly correlated to our visual perception and experience of physical form and space.

This investigation narrowed its scope of work to the physical representations of Western music. Further investigation could test how well the “Melodic Experience” method of form-making renders music of non-Western cultures. This would implement an entirely new set of parameters, and possibly refine the overall process of construction.

The “Melodic Experience” was only analyzed for its effectiveness in expressing the primary elements of music that are needed to satisfy the basic definition of music. Revisiting Benjamin Boretz’s *Meta-variations: Studies in the Foundations of Musical*

Thought, the primary elements of music are rhythm, harmony, melody, structure, form, and texture.[28] This study did not analyze how the "Melodic Experience" expressed the musical elements of structure, form, and texture. Because the "Melodic Experience" was tested using established musical compositions, the structuring of the songs were already inherent in their design; they could in turn, be analyzed to see how well they expressed that musical structure. The "Melodic Experience" method, was tested on portions of select song's, with an emphasis on capturing the primary melodic lines of each. To analyze song-form, the entire musical composition would have to be constructed; however, the diagram below depicts how the "Melodic Experience" begins to express the song-form and structure of "B.Y.O.B." by System of a Down.



EXPRESSIONS OF
STRUCTURE & FORM
IN THE MELODIC EXPERIENCE
OF "B.Y.O.B" BY SYSTEM OF A DOWN

The final primary element of music that was not completely addressed through this investigation was the element of texture, which "refers to the way multiple voices

---

[28] Boretz, Benjamin, *Meta-variations: Studies in the Foundations of Musical Thought* (New York: Open Space, 1995).

(or instruments) interact in a composition."[29] The idea of musical texture closely overlaps the idea of musical harmony; the primary difference being that texture looks at the way in which pitches interact, and harmony is simply when two or more pitches sound simultaneously. The "Melodic Experience" method of form-making adapted to the element of texture by composing a two-part form that expressed a songs melody and accompaniment.

Further investigation could analyze specifically how structure, form, and texture (and any/all musical elements) are expressed through the "Melodic Experience." Any conclusions of that analysis could then be reapplied to the "Melodic Experience" method of form-making, as a refinement to its final expression of form. This text disclosed how the system adapted to the musical elements of harmony, and rests, demonstrating how specific qualities may be adopted without altering the overall method of form-making.

In constructing the methods for the "Melodic Experience," attention was focused on replicating the experience of listening to music, by directly correlating our auditory perception of music to our visual perception of space and matter; however, what is the "Melodic Experience's" real application to architecture? If the original intention of reproducing a music-like experience is to remain intact, then these forms can only be applied to walkable pathways; such as corridors, walkways, or footbridges.

[29] Mid-South Community College. "MUSICAL TEXTURE." Shared Learning Objects. learn.midsouthcc.edu/LearningObjects/Music_Appreciation/musicaltexture/Musical_Texture.html (accessed December 6, 2012).

However, if the original intention is set aside, then its applications become extensive. The forms of the “Melodic Experience” are founded on proportional relationships between musical pitches; therefore, they will preserve those proportional relationships regardless of their scale. Whether the forms are applied to the texture of a surface, or to the overall form of a building, their formal relationships will express musical proportions. As such, the true discovery of this thesis resides in the application of musical proportions to the proportions of the built environment, paving the way for future interpretation. This thesis stands as part of the growing methodologies in form making, and contributes to the future development of how music can render physical form and articulate architectural design.

Music Theory of the West

Fundamentals

This section introduces the way in which Western culture developed a succinct musical system. Music theory is exceptionally complex, with nearly infinite intricacies that define its parameters. The intent of this section is to impart a basic understanding of Western musical theory, and aid in the conception of the transition from music to three-dimensional form. This basic understanding will serve a great deal of importance to those with little musical training, and provide a foundation for further discussions in the text. The following will convey the primary concepts that dictate the realm of sound, and articulate the theory of music conjured through the eyes and ears of Western culture.

To fully understand music theory of any culture one should study multiple texts that specifically edify musical concepts, listen to numerous examples of those concepts in action, and physically play them on a musical instrument. This simple fact reiterates the 'overlap theory' previously mentioned, where true understanding is conceived through multiple avenues of exploration. An attempt to comprehend music theory entirely through textual applications would result in a fractured perception of what music really is, and how it is structured.

Sound

Sound, a mechanical or longitudinal (when moving through air) wave of pressure variation, is quantified by frequency (Hertz – number of vibrations per second), wavelength (Distance Units – typically in centimeters), and intensity (Energy per Time * Area, or, Power per Area). Intensity is measured using the logarithmic decibel scale; therefore, the decibel unit of a sound refers to its intensity level. Intensity is analogous to volume level, and corresponds to the actual amplitude of the sound wave. Sound is propagated by a disturbance in a given medium by a vibrating object, such as a vibrating string or our vocal chords. In short, the study of sound mechanics, acoustics, and psychoacoustics, show us that sound vibrations take shape in waveforms. Pure tones (which music is founded on) take the shape of sinusoidal waveforms, or sine waves. A specific sounds frequency actually refers to the number of times its wave pushes air over our eardrums every second. Consequently, a pitch at 440 Hz. vibrates the air in our ear eardrums 440 times every second, while preceptors within our ears, transmit the wave's pressure differentials to our brain, through electrical signals.[30] The typical range of human hearing resides between 20 Hz. and 20,000 Hz; this is known as the audible range of sound. Frequencies below the audible range are referred to as infrasound and frequencies above it as ultrasound.[31]

---

[30] AAC ~ The Audiology Awareness Campaign. "How We Hear: External, Middle & Inner Ear." Audiology Awareness Campaign. http://www.audiologyawareness.com/hearinfo_howhear.asp (accessed April 15, 2011).

[31] comPADRE. "Sound Waves and Music." The Physics Classroom. http://www.physicsclassroom.com/class/sound/ (accessed April 19, 2011); Mark Ballora. "Pitch Vs.

Frequency and wavelength retain an inverse relationship. When a frequency is doubled, its wavelength is halved, which means twice as many waves are vibrating in our ears every second. When two sounds oscillate in our eardrums in the same manner, they are perceived as the same sound, hence the realization of the octave. In music, the octaves of a given pitch/note sound so similar; they are even given the same name. An octave above a given pitch has a frequency ratio of 2:1, while a double octave has a ratio of 4:1, and a triple octave at 8:1; the inverse of these ratios would transition the pitch down in octaves. The reason these pitches are recognized as the same sound, is because their wavelengths have been sequentially halved, or doubled.

The octave is one of the many *intervals* of musical pitches. An interval is "the 'distance' or relationship between two pitches."[32] Interval names start with unison, where there is no change in pitch from one tone to the next. They then move sequentially in integers (whole numbers – 2nd, 3rd, 4th, … 7th) through the octave, at which point they start again. Intervals are always in reference to a starting point, typically the first note in a scale (the keynote), and have slight variations off their integer names indicating a slight change in pitch, such as a major or minor third. Greater understanding of the interval will unveil throughout the text.

The perception of the octave is one notion that stands true within all cultures of the world, it is a physiological phenomenon and stands as a foundation for musical

---

Frequency." Electronic Musician. http://emusician.com/tutorials/emusic_pitch_vs_frequency/ (accessed April 19, 2011); Carl Rod Nave. "Sensitivity of Human Ear." HyperPhysics. http://hyperphysics.phy-astr.gsu.edu/hbase/sound/earsens.html (accessed April 19, 2011).

[32] Gary C. White. "Glossary." In *Music first!*. 5th ed. Boston: McGraw-Hill, 2007. 317.

order. What sets musical order of different cultures apart (and even within the West, before a standard was adapted), is the way in which the intervals between octaves are divided. Theoretically, an octave can be divided into an infinite number of intervals; however, the smaller the interval between two pitches the more difficult it becomes for the brain to distinguish the difference between the two pitches.

It is important to distinguish the difference between the terms note, tone, and pitch, as to eliminate confusion in there uses. At times they are used interchangeably; however, each term does carry a specific origin and reference. The term note refers to a single sound or tone with no discernible pitch. The term also references a symbol or character given to a specific sound; such as the notation symbols used in musical scores. In addition, the term refers to the name given to a pitch class. In Western music, the notes have been defined by the letters A through G. When spoken, an 'A' can reference any 'A' within the audible range, and when written in notation, it refers to the specific frequency that note has been assigned. A tone is a single sound with a discernible pitch. Tone also refers to the quality or timbre (tone color) of a sound. This is what sets different instruments apart from one another; they produce vibrations of the same frequency yet have a different tonal quality or 'feel.' The term pitch is generally used to describe the relative 'highness' or 'lowness' of a musical sound, such as an "A above middle-C," or "a high-pitched sound." However, once a standard has been set, dictating that all musical tones have a definitive frequency (this differs between cultures and tuning styles), the term pitch, then directly refers to the frequency of that specific note.[33]

Tonality

Nearly all Western music (and music from many other cultures) is based on a 'tonal' system; more accurately referred to as *Western Tonal Music*. [This thesis and the explorations therein, will focus primarily on this system. To eliminate confusion, anytime this text refers to music of the West, it is referring to the ideology that governs Western tonal music.] The principle dictating tonal music is that one note or pitch plays a predominant role to all other notes in the piece (musical composition).[34] The word tonic is derived from this principle, and refers to this one important note (or chords built on it), which is always the first note in a scale; also called the keynote. Referring to music as tonal also alludes to the notion that it is constructed within an identifiable key,[35] where identification is only made possible because of the tonics significance within the

---

[33] Gary C. White, David Stuart, and Elyn Aviva. *Music in Our World: An Active-Listening Approach*. Boston: McGraw Hill, 2001; Gary C. White. *Music first!*. 5th ed. Boston: McGraw-Hill, 2007; David Pogue, and Scott Speck. *Classical Music for Dummies*. Foster City, CA: IDG Books Worldwide, 1997; George Thaddeus Jones. *Music Theory* . New York: Barnes & Noble Books, 1974; Larry J. Solomon. "Solomon's Glossary of Technical Musical Terms." Solomons Music Theory Resources. http://solomonsmusic.net/glossary.htm (accessed April 19, 2011); ClassicalWorks. "Glossary of Musical Terms." Music History and Timeline at Classical Works. http://www.classicalworks.com/html/glossary.html (accessed April 19, 2011); "Glossary of Musical Terms." San Francisco Classical Voice. http://www.sfcv.org/learn/glossary/p (accessed April 19, 2011); Dictionary.com | Free Online Dictionary for English Definitions. http://dictionary.reference.com (accessed April 19, 2011).

[34] Mike McFerron. "Tonal Music." Mike McFerron. http://www.bigcomposer.com/module/lectures/keysignatures1.pdf (accessed April 14, 2011).

[35] David Pogue and Scott Speck. "Appendix C: Glossary." In *Classical Music for Dummies*. Foster City, CA: IDG Books Worldwide, 1997. 335.

structure of the composition. The octave of the keynote lives vicariously through the tonic in its significance. The other notes and chords within a tonal piece of music, will often revolve around the tonic, and resolve to it. The tonic is usually the final note/chord in Western tonal music, as it resonates with our sense of cadence. Music that is not based on this tonal system is referred to as *atonal* music.

Consonance vs. Dissonance

This brings us to the principles of *consonance* and *dissonance,* where combinations of musical pitches have been characterized by their emotive qualities. The ideals of consonance and dissonance really speak to the relationship between two or more pitches sounding simultaneously. The concurrent sound of two pitches is referred to as *harmony.* The term *interval,* describes the distance between two notes, or moreover, the ratio between the frequencies of those two notes. When three or more pitches sound in unison, the sound is referred to as a *chord*.

Consonance, rooted in the Latin word *consonantia* or *consonare* (*com-*, "with" + *sonare*, "to sound"),[36] is analogous to stability. Intervals and chords are said to be in consonance if they sound stable. We can hear sounds in consonance and feel at ease, they are stationary, pleasant to the ear, and do not appear as though they want to move to another sound.

[36] "Consonance." Dictionary.com | Free Online Dictionary for English Definitions. http://dictionary.reference.com/browse/consonance (accessed April 14, 2011).

Dissonance, rooted in the Latin word dissonantia or dissonare (dis-, "apart" + sonare, "to sound")[37] speaks to an element that is considered unstable. Intervals and chords in dissonance, make us feel uneasy or anxious, and are typically unpleasant to the ear. Dissonant intervals and chords want to move, and are not settled until they find an interval or chord in consonance. This is a simple definition in the concept of resolution, and testifies to the doctrines of *cadence*.

The principles of consonance and dissonance are prevalent in tonal music of all cultures; however, due to social and musical conditioning, our minds perceive sound in a particular manner. Our brains are accustomed to hearing certain pitches and patterns, or movements there in; thus the minds rebellion in adapting to musical styles of other cultures. Studies have shown "that the human perception of consonance and dissonance is learned from exposure to actual human speech."[38] It is still debated whether this is strictly due to conditioning, or attained through an actual evolutionary process. Regardless, we all have our own sense of consonance and dissonance, from music, to visual arts, to architecture. It is not eternal either; our perception grows and changes, as all things do in life.

[37] "Dissonance." Dictionary.com | Free Online Dictionary for English Definitions. http://dictionary.reference.com/browse/dissonance (accessed April 14, 2011).
[38] Philip Dorrell. "What is Music? Development: Statistical Structure of Human Speech Sounds and Calibration of Interval Perception." What is Music? http://whatismusic.info/developments/StatisticalStructure.html (accessed April 17, 2011).

Harmony

Western perception of musical consonance is rooted in "the natural harmonic, or overtone, series, which results from a vibrating string or air column... [while musical consonance of] certain Eastern cultures … are melodically oriented."[39] "Western-style harmony is generally known as tonal harmony because it creates a sense of tonal center or key."[40] The fundamental concept and theory behind musical harmony is fairly simple in its definition; however, due to the wide variety of its application in musical compositions, it can prove itself to be quite difficult to fully grasp, and frankly arduous an undertaking.

The most basic definitions of harmony are, "any simultaneous combination of tones,"[41] or, "the study of tones sounding together."[42] Neither of these definitions explain much in the use and application of harmony. The text, Classical Music for Dummies, defines harmony as "the particular chord that plays in the background while a melody is playing. Also, the study of chord progressions."[43] This starts to touch on the concept of harmony; however, the musical background in a piece is better defined as an

---

[39] George Thaddeus Jones. "Chords." In *Music Theory* . New York: Barnes & Noble Books, 1974. 43.
[40] Gary C. White, David Stuart, and Elyn Aviva. "Music in Society." In *Music in Our World: An Active-Listening Approach*. Boston: McGraw Hill, 2001. 171.
[41] Harmony. Dictionary.com. *Dictionary.com Unabridged*. Random House, Inc. http://dictionary.reference.com/browse/harmony (accessed: April 17, 2011).
[42] Gary C. White. "Chords – Looking at the Musical Background." In *Music first!*. 5th ed. Boston: McGraw-Hill, 2007. 172.
[43] David Pogue and Scott Speck. "Appendix C: Glossary." In *Classical Music for Dummies*. Foster City, CA: IDG Books Worldwide, 1997. 335.

accompaniment which is without a doubt harmoniously linked to the melody of the piece.

The fundamental principle in harmonic development (noted above) is founded on what is known as the natural harmonic series. Concerning music, this is typically referred to as the overtone series. The image below depicts the mathematical equivalent of the harmonic series. Each number in the series is based on the division of a strings fundamental frequency, which in turn gives us our ‘perfect’ intervals, or the overtone series. In short, “the term harmonic series specifically refers to a series of numbers related by whole-number ratios.”[44] What is beautifully fascinating, is the fact that the series itself is derived from a completely natural phenomenon, found within a vibrating string or air column.

$$\sum_{n=1}^{\infty} \frac{1}{n} = 1 + \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \cdots + \frac{1}{n} + \cdots$$ [45]

To understand this concept we must break it down into digestible steps. If you have a guitar, or any stringed instrument, you can actually follow along and test this theory yourself. This phenomenon can be observed on any string that is bounded at both ends and stretched taught enough to produce a pitch. If you touch your finger to the string ever so lightly, so that your fingertip just barely makes contact with the string,

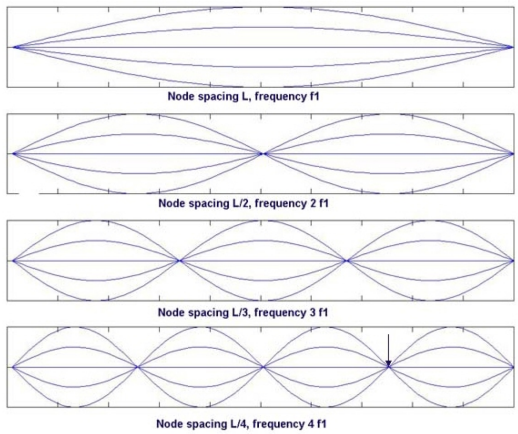
[44] Reginald Bain. "The Harmonic Series." A Web-based Multimedia Approach to the Harmonic Series. www.music.sc.edu/fs/bain/atmi02/hs/index-audio.html (accessed April 17, 2011).
[45] Math Academy Online™ / Platonic Realms™. "Series -- Types and Tests ." PRIME: Platonic Realms Interactive Mathematics Encyclopedia. http://www.mathacademy.com/pr/prime/articles/serie/index.asp (accessed April 17, 2011).

and pluck the string you will most likely hear a muted thud; an unpleasant sound with no definitive pitch. If you move your finger up and down the string, you will find areas where a pleasant sound is produced (if you just so happened to land on one of those places when you first put your finger to the string, than congratulations, you must be harmonically in tune with nature). The points where a sound actually resonates from the string only happens at key locations. The unique sounds fashioned through this technique are coincidently known as harmonics, because you are actually hearing two tones simultaneously: the vibration of the full length of the string along with the vibration of the division of the string.

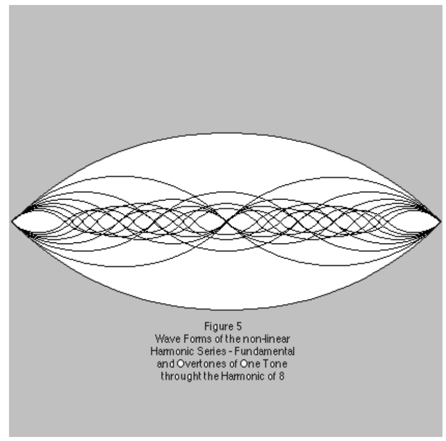
To run through this example we are going to use the low E string on a guitar, which has a 'just frequency' of 82.5 Hz (the term 'just' with regards to frequency will be explained after this exercise and you can still test, or moreover, hear the physical phenomenon of this theory without knowing the pitch of the string). This is known as the fundamental frequency (f) and the overall length (L) of the string will be set as 1; thus our initial ratio is 1:1 with the formula 1L = 1f.

If we place our finger lightly on the middle of the string (between the 12th and the 13th frets), we divide the string into two equal parts. We are hearing the entire string vibrate, however, it is not vibrating where our finger is touching the string; this dead point, where no vibration occurs, is referred to as a node. The harmonic we hear, is known as the second harmonic, and the pitch sounding has a frequency that is twice the fundamental. Our ratio for this harmonic is 1:2 (one part to two parts), with the formula

$^{1}/_{2}$ L = 2f. When we push down on the 12th fret and pluck the string, we are still playing half of the strings length; thus, the tone has the same frequency as the harmonic at 165 Hz, which is an octave from our fundamental at 82.5 Hz.



[46]



[47]

Now let us divide the string into thirds. This harmonic is located between the 7th and 8th fret or the 19th and 20th fret. It is easier to play off the 7th fret, but notice that they produce the same sound. Examine that we can also play the harmonic on one of these nodes, release the string, and touch the other node without the sound breaking. If we touch the string anywhere else but these nodes, the sound will cease. This is because the string is literally being divided into three equal segments. The images above depict the divisions that take place when we touch one of these nodes. If we push down on the 19th fret and pluck the string, we hear the same tone, which is $^{1}/_{3}$ of the string; thus the ratio for the third harmonic is 3:1 (three parts to one part), with the formula $^{1}/_{3}$ L = 3f,

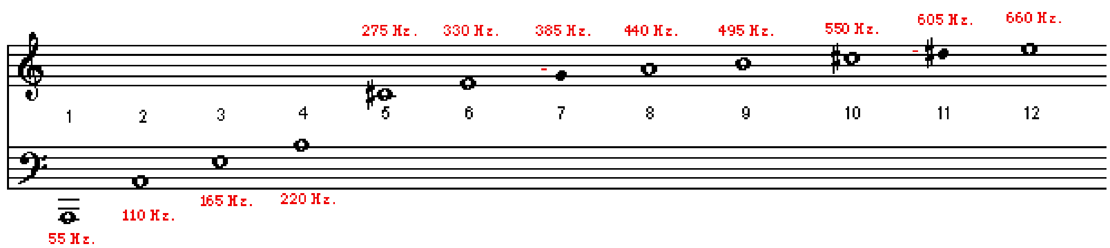
---

[46] Mark A. Peterson. "The Vibrating String." Mount Holyoke College, South Hadley, Massachusetts. http://www.mtholyoke.edu/courses/mpeterso/galileo/interval.html (accessed April 18, 2011).
[47] Jack Logan and Danlee Mitchell. "Elements of Music - Part One." Music in Our World. http://trumpet.sdsu.edu/M151/Elements_of_Music1.html (accessed April 22, 2011).

dictating a frequency of 274.5 Hz (B above the octave of our fundamental frequency E). Now, if we push down on the 7th fret and pluck the string, we are playing $^{2}/_{3}$ of the string; as a result, our ratio becomes 3:2 with the formula $^{2}/_{3}$ L = $^{3}/_{2}$ f, giving us a frequency of 123.75 Hz (B above our fundamental frequency E).

The fourth harmonic follows the same process giving us the ratios 4:1 (a double octave above our fundamental frequency E) and 4:3 (an A above our fundamental frequency E). Observe that if you pluck the fourth harmonic you can touch the string at any of the nodes and the sound remains constant. One of the nodes falls on the midpoint, where our second harmonic is. If you pluck the second harmonic, and then touch any of the fourth harmonic nodes, the string is divided into four vibrating segments and the fourth harmonic rings.

This process theoretically continues to infinity, however, without the aid of electronic amplification it is hard to make out the tones even past the fifth harmonic. This series depicts the way in which intervals are defined by nature. Remember, this process works in succession; consequently, each interval is defined by the last. The second harmonic is an octave above the fundamental with a ratio of 2:1, the third harmonic has a ratio of 3:2 from the second, the fourth harmonic has a ratio of 4:3 from the third, and the fifth harmonic has a ratio of 5:4 from the fourth, and so on. These ratios stand true whether we move sequentially through the harmonic series or play the shortened part of the string by pressing down hard on the fret board. In the instances where we actually press on the string, we play the interval directly above the fundamental frequency; as such, these ratios can then be applied to any pitch to get the corresponding interval. The image below depicts the harmonic series expressed on the musical staves; this series has been constructed off an A, at 55 Hz., where as we started with the low E on a guitar at 82.5 Hz. This sequence is known as the overtone series, and gives us every interval possible. Observe the relationship between any two numbers in the sequence and their corresponding frequencies.



48

"Our sense of consonance, concordance, or agreement comes from the lowest six tones of the overtone series that produce a major triad."[49] These intervals are referred to as the octave, the perfect fifth, the perfect fourth, the major third and the minor third. Dating back to the Middle Ages, thirds were not considered consonant; they were not adapted until harmony based around the triad, became common practice. Because this notion of adaptation, and because the overtone series produces all intervals possible (even ones that are not used in the Western tempered system) we can delineate that consonance and dissonance are relative and subjective terms. There is undoubtedly a common understanding, or a majority rules quota, regarding our sense

[48] Reginald Bain. "The Harmonic Series." A Web-based Multimedia Approach to the Harmonic Series. www.music.sc.edu/fs/bain/atmi02/hs/index-audio.html (accessed April 17, 2011).
[49] George Thaddeus Jones. "Chords." In *Music Theory* . New York: Barnes & Noble Books, 1974. 43.

of consonance/dissonance; however, it is impossible to say that they are definitive in their perception.

Western Keys + Scales

We may now identify the specific way in which Western culture has developed an explicit musical structure of sound. Western music is constructed around the principle of the octave in that the frequencies that lie between a keynote and its octave are divided into twelve equal parts. An individual pitch (frequency) in this set of pitches is referred to as a semitone, a half tone, or a half step. These terms are interchangeable when discussing the interval between two adjacent notes in the 12-tone musical scale of the West. Each semitone is given a lettered name and classified as a musical tone. The letters are A, $A^{\#}$ (B^{b}), B, C, $C^{\#}$ (D^{b}), D, $D^{\#}$ (E^{b}), E, F, $F^{\#}$ (G^{b}), G, and $G^{\#}$ (A^{b}). The sequence then returns to A at the octave. The sharps (#) and flats (b) are used to indicate a rise or fall in a single semitone. The notes in the parentheses refer to enharmonic equivalents, where a musical note can be referenced through any other note using sharps and flats. Without digging too deep into musical conundrums (humorously and technically you could refer to a C as an $A^{\#\#\#}$ or a D^{bb}), the appropriate use of sharps and flats is stressed when referring to specific keys of musical scales. A Western major scale must always use each note once (A through G), regardless of what letter/note you start on. Minor scales of the West follow the same principle with the exception of the melodic minor scale, which has an ascending structure (moves up in pitch through the octave), and descending structure (moves down in pitch from the octave to the tonic/keynote).

The fundamental reasoning for dividing an octave into twelve equal parts, was to enable a composer to change keys in the middle of a composition without having to retune the instruments. Ironically enough, the harmonic series only dictates 'perfect' intervals within a single system; a key based on one fundamental root or pitch. If you start the series on a different pitch, the intervals will not be in accordance with the other series. This meant that instruments tuned by the natural harmonic system (or the 'just scale') could only play within the key they were tuned in, and could not change keys without retuning. In sue of composer's desire for greater musical variety, it was decided to do away with the natural series in turn for a system of equal division. Thus, the system of equal temperament was born in lieu of the later system, referred to as the just scale.

The process that devised all of the key signatures came from the circle of fifths. This process is based off harmonics and proper cadence (this will be discussed latter in the text), which is founded on the principles of resolution, or moreover, the movement from a dissonant sound to a consonant one (unsteady to stable). In brief, the most powerful resolution is achieved by moving down a perfect fifth from a major seventh chord. Typically, this cadence is achieved in a major scale in the movement from a V7 (dominant) chord to a I (tonic) triad. If you then add a minor 7th to this 'tonic' chord, you get a new note that is not in the original scale. If you started in the scale or key of C-Major (C-Major has no sharps or flats and is considered the foundation of all other keys and scales because of the following process) the dominant 7th chord (V7) is a G7-Major;

consisting of the notes G-B-D-F. The tonic triad (I) in this scale is C-Major, consisting of the notes C-E-G. If you add a minor seventh to this triad, you add a B^b to the chord, which is not in the C-Major scale. A perfect fifth down from the root (C) of this new chord is F. If you build a major triad on F, and F-Major becomes the new tonic with C7-Major the dominant seventh than a new key and major scale emerges. This new scale and key becomes F-Major, and has one flat on B. This major scale of E would precede F-G-A- B^b-C-D- E-F. If you add a minor seventh to the F-Major triad, you get another new note that is not in this scale. This new note is E^b. A perfect fifth down from F is Bb; thus, the scale and key of B^b-Major has two flats, one on B and one on E. The major scale of B^b would precede as such, B^b-C-D- E^b-F-G-A- B^b.

This process continues until we come full circle to the key of C-Major. If you follow a similar process by moving up in perfect fourths, we would get all of the sharps in the keys. This process is still dictated and governed by the notions of harmony, in that the interval movements are based on perfect fifths and fourths. It is this process that truly determined the reasoning for twelve notes between an octave; the decision to divide them evenly, was based solely on the desire to change keys without retuning. A specific scale can be memorized simply by the steps that define it (a major scale proceeds – Whole step, Whole step, Half step, W, W, W, H), nonetheless, we now understand the process that created the twelve tones of the chromatic scale (Half steps up to the octave covering all of the tones between an octave in Western tonal music).

That concludes our flythrough tutorial on music theory of the West. Other principles and patterns will emerge throughout the text; however, we now have a decent understanding of the, ‘how’ and, ‘why’ music has been structured in Western culture.

Correlations

The parallels that exist between music and architecture have been noted throughout history; however, little has been documented in the process of how a three-dimensional creation can represent the qualities of music. This section will analyze the intersections of music and architecture; locating these connections will reveal their similarities and differences, and held the reader develop an understanding of how the two correlate. Awareness of how these progressive mediums overlap will make way for new strands of thought, where music may begin to shape three-dimensional form and space to develop architecture as a direct expression of music.

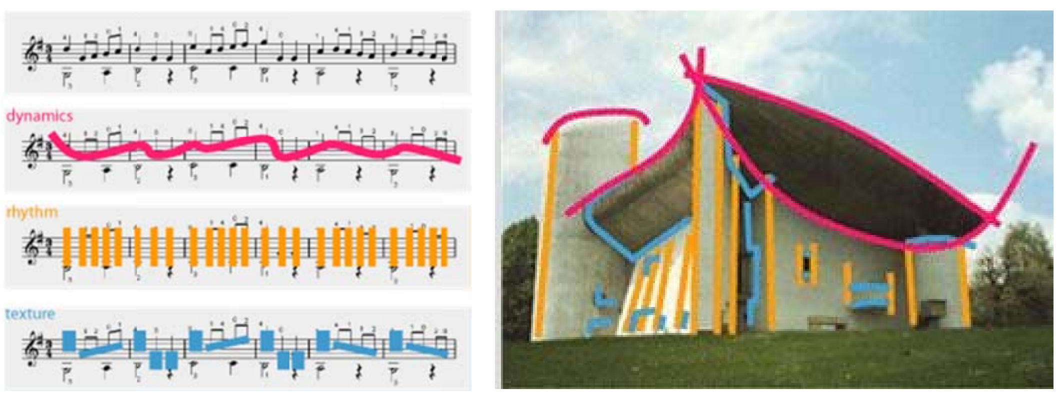
Acoustics

The most prevalent architectural response to music is the adaptation of acoustical qualities. Acoustical engineering has shaped architectural design through the formation of amphitheaters, cathedrals, conference rooms, and even train stations and sound rooms. It has also aided in the design of acoustical instruments. The desire for ultimate control over acoustics – the ability to amplify, mitigate, or alter a quality of sound transmissions – has driven mathematicians, physicists, chemists, architects, and musicians to shape the physical form of both space and material.

The use of acoustics within the fields of music and architecture draws a strong comparison between the two; however, it does not define architecture as a physical representation of music. This thesis aspires to define methods of translating musical concepts and musical structuring directly to the physical rendering of three-dimensional form. The study of acoustics offers insight into the physics of sound and the way music interacts with the physical environment; nonetheless, acoustical engineering was not the primary concern of this investigation.

Terminology

Music and architecture share many similar qualities and specific terms when defining the constituent parts of their makeup. These terms include point, line, frame, rhythm, material, texture, dynamics, structure, composition, form, aesthetics, harmony…; the list is virtually endless. The following graphical representations analyze how the qualities of rhythm, texture, and dynamics are expressed through both a musical score and on Notre Dame du Haut, designed by Le Corbusier.

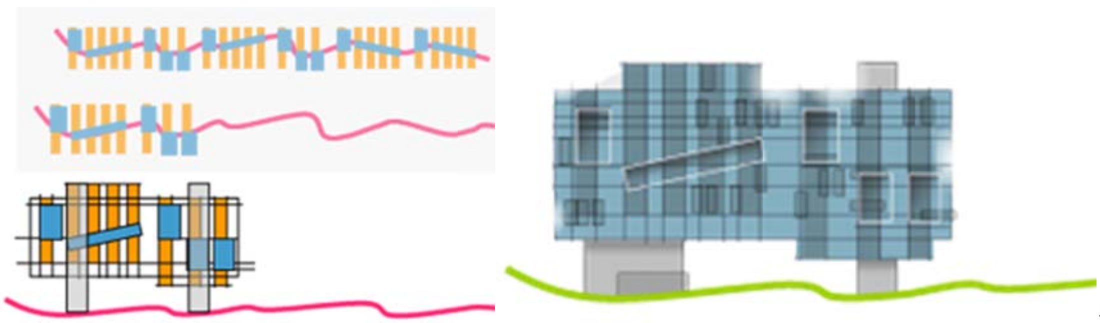


[50]

Similar terminology is used to describe qualities of the two mediums; it is interesting that there are so many overlapping designations between music and architecture. But describing the two in a similar fashion does not necessarily make

[50] "Music and Architecture." NEXT.cc. http://www.next.cc/journey/discovery/music-and-architecture (accessed September 20, 2012).

architecture musical. Only if the terminology were used to define specific aspects of musical compositions, and those specific aspects were then directly applied to the design of architecture, would the architectural composition begin to demonstrate and convey the concepts of music. The following diagrams depict a very literal application of analytical notation to the design of an architectural piece:



[51]

Though simplistic in its conception and execution, this design can be analyzed using the musical definitions of the common terminology between music and architecture, and begins to speak the language of music through physical form. It is important to realize that the specific way music is composed is what defines its character, not the terminology that is used to analyze and describe it. However, knowing the analytical language of music will aid in a designer's ability to demonstrate musical concepts through architectural form.

[51] "Music and Architecture." NEXT.cc. http://www.next.cc/journey/discovery/music-and-architecture (accessed September 20, 2012).

Purpose

Do music and architecture have a purpose?

What is the purpose of music? Music is created for many reasons and serves multiple purposes. The function of a particular piece of music is dictated by society, thus establishing a role in a given setting. According to the text *Music in Our World: An Active Listening Approach,* these purposes include: [52]

Religion – music created for a religious event;

Spirituality – music that is psychologically uplifting, that it takes you to a higher state of consciousness;

Group cohesion – music that is meant to physically bring people together;

Utilitarian functions – music that promotes and coordinates physical action;

Communicating verbal and nonverbal messages – music that tells a story or aids in its delivery;

Entertainment – music that is created to give an overall enjoyable experience;

Motivation – music that deliberately moves a listener to take action;

Artistic expression (Art Music) – music that doesn't perform a specific function but simply resides as human creation; music for the sake of music.;

In many cases, these purposes overlap. That is to say, music can serve multiple purposes at the same time, enriching its intrinsic value: "Much of the music of all cultures is utilitarian: that is, it serves a purpose beyond simply being listened to for its

[52] Gary C. White, David Stuart, and Elyn Aviva. "Music in Society." In *Music in Our World: An Active-Listening Approach*. Boston: McGraw Hill, 2001. 17.

own sake."[53] Utilitarian music enhances the experience of a given task; it takes the form of work songs, band marches, parade music, exercise music, and any other function that is enhanced by the music itself.

It is not hard to distinguish similarities in the reasons music and architecture are created. All of the aforementioned purposes can be perceived in architectural endeavors: church design for religious events, conveying a sense of spirituality; conference rooms and auditoriums for group cohesion; theatres and parks for entertainment; office buildings for utilitarian functions; architecture that tells a story; or a structure that simply stands as human creation. There are countless examples that can showcase similar determinations of music and architecture; however, the most basic purpose of architecture is to create shelter. From that founding principle, architecture grew into a means of housing our human needs and aided in accomplishing a multitude of tasks. In the same way that utilitarian music enhances an experience, architecture should (and in most cases, is) designed to engage and improve the tasks it houses.

One distinction that touches on all of the purposes listed above is engagement with humans; both music and architecture enhance a quality of life. Architecture can be created as "art;" however, it almost always serves a purpose. Music and architecture as art also stand as viable means of human expression; they encompass our creative ingenuity and most definitely add to our quality of life. It can thus be stated that any creative media that captures artistic expression while serving a utilitarian function

[53] Gary C. White, David Stuart, and Elyn Aviva. "Music in Society." In *Music in Our World: An Active-Listening Approach*. Boston: McGraw Hill, 2001. 17.

provides a greater value to society. Therefore, “Artistic-ultilitarianism” should be at the heart of all design professionals.

An interesting aspect of both music and architecture is that they can be used to represent a deeper meaning, or engage their audience to evoke specific emotive qualities. We see this with regard to company branding. A retailer will wisely choose the background music of a commercial to create a desired image for their product. The same mentality is followed in the style of architecture that will display their product. For example, a luxurious product may be presented with classical music in a slick black display window, where a product for kids may be displayed with a playful jingle on a jungle gym. How would our perception of the products change if the music and/or setting of the two were swapped?

Music can be used to enhance our overall perception of an experience. The same can be said about architecture through its spatial design and use of materials. The primary difference is that architecture stimulates our visual senses, while music engages our auditory senses. Architects and composers have the ability to fashion a given perception through the design of their art. This can be used to enhance the purpose of their medium and bring greater depth to their design.

Human Response

There are four basic human reactions to music: physical, emotional, cognitive, and spiritual. These responses can overlap at times. The human response to music may be more inherent or easier to perceive than in architecture; however, the responce is undoubtedly present.

Physical response to music is perhaps the most basic and most prevalent human reaction. Typically, this response is due to the musical element of rhythm. We often respond subconsciously, without out even trying or noticing. We tap our feet to the beat, or nod our head; in the obvious extreme, we dance to music, consciously syncopating our body's movements to a tempo. Music also carries a more subtle physical response: when we listen to calm music, the muscles in our body tend to relax, we feel tranquil. Studies have even shown that music can affect our heart rate, our respiration, and our brain activity.[54]

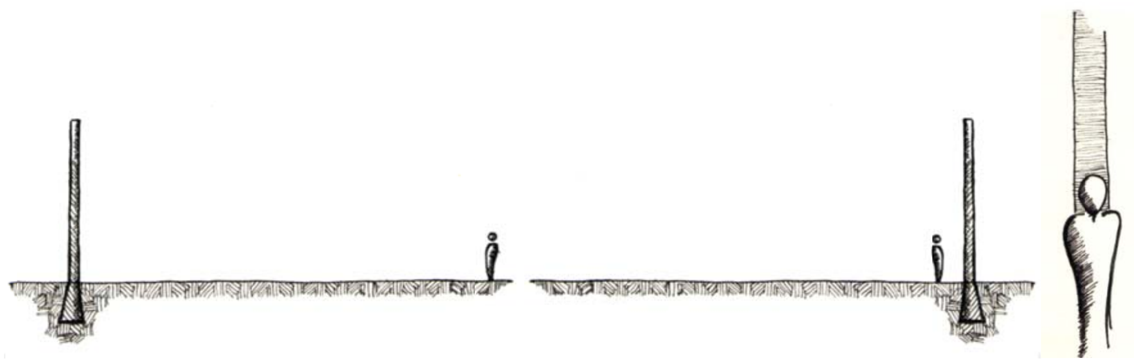
Can architecture create a similar physical response? Perhaps not one as prominent, but space itself and our position relative to objects around us most definitely evokes a physical response. Architecture in itself is physical; therefore, we automatically have a physical interaction with respect to it.

Let us first deal with the stationary condition, where we are in or next to a physical form without moving. Proxemics plays a huge role in our physical response to objects in space. Say there is a single wall on a flat plane; the wall is a foot thick, ten feet long, and thirty feet tall. Our physical response is going to vary greatly depending on our position relative to the wall. If we stand fifty feet away from the face of the wall, its' physical impacts are minimal; our only reaction might be that it blocks part of our view.

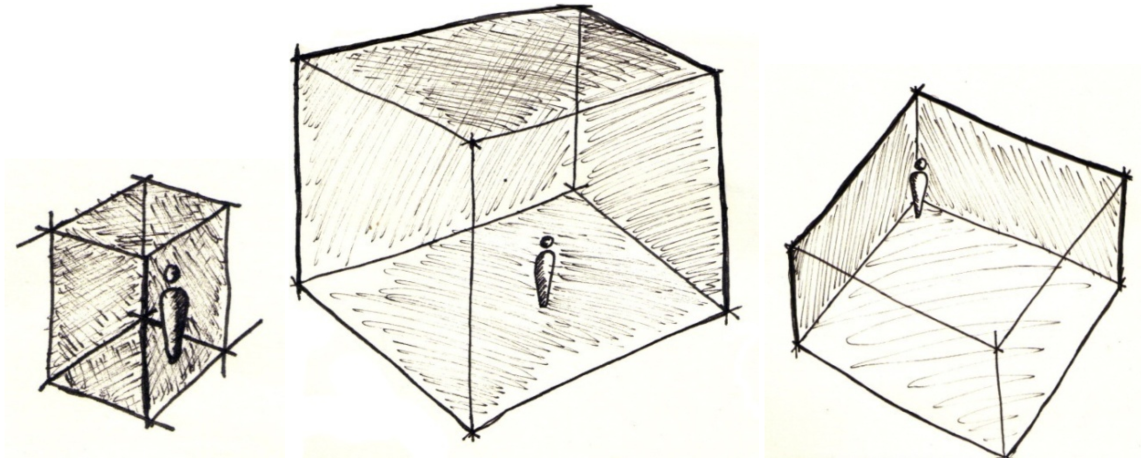
---

[54] Gary C. White, David Stuart, and Elyn Aviva. "Our Response to Music." *In Music in Our World: An Active-Listening Approach*. Boston: McGraw Hill, 2001.

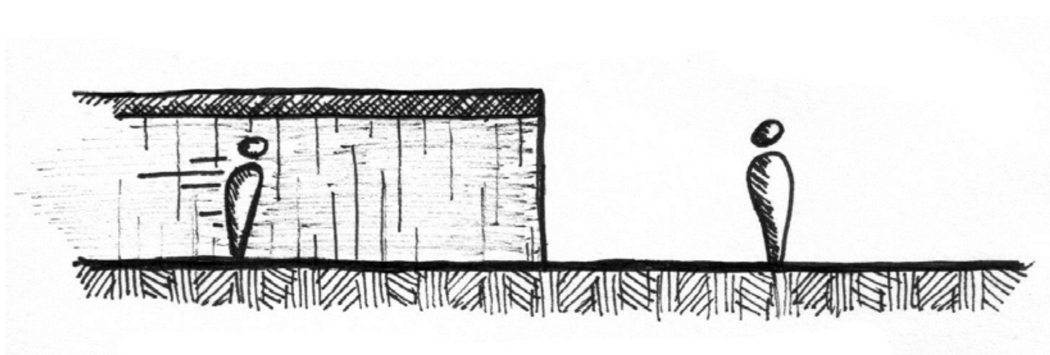
However, if we stand right next to the face of the wall, we feel its presence towering over us; we may feel uneasy, or may turn away from the wall or even lean towards it to counteract this feeling. If we were to stand on the side of the wall, its impact is minimized, because we are only reacting to its thickness.

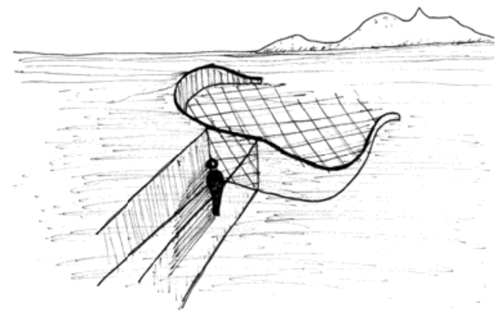


Now imagine being inside a space – a square room with all sides and roof enclosed. The scale of that room is going to affect your physical response. If the room is confined (not much bigger than you are), you will begin to feel claustrophobic, and you will most likely want to physically remove yourself from the space. If the room is much larger than you are, then again your position relative to the space changes your physical response. If you are in the center of the room, you may feel open and relieved. Depending on the scale of the room, you may also feel vulnerable and unprotected in the open space; you may feel more comfortable in the corner of the room looking out over the space. Architecture and space have three dimensions, so the distance of objects on all sides of you and the distance of objects above you will change your physical response to the space.



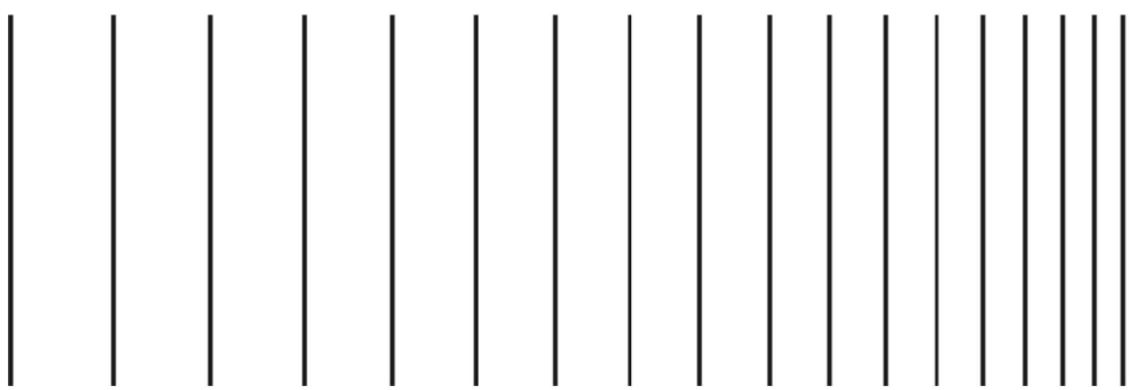
When the fourth dimension of time is added to the experience of a space, its effects on our physical response are greatly enhanced. As noted above, a space may provoke you to move to an area where you are more physically comfortable. The element of time coexists with our movement in, around, or through a space. We have the ability to change the way we feel by physically moving ourselves relative to physical objects around us. A designer of space has the ability to force a physical response out of the user. The concept of compression-release, where a patron moves from a confined space into an open space, serves as a perfect example.





The effect creates a feeling of relief as the patron moves from a spaciously restricting area to one that is open; the greater the contrast between the spaces, the greater the effect. There are infinite combinations in adapting space to provoke a physical response; knowing how a space or a combination of spaces will affect a person is an invaluable resource when designing architecture.

Our primary physical response to music is subject to audible rhythms. We act upon these rhythms by physically moving to the beats.[55] Our minds are also perceptive to *visual* rhythms, giving them the potential to evoke similar physical responses. Look at the set of vertical lines below. On the left, they are spaced out a given amount and as they progress to the right, they get incrementally closer.



As your eyes move across the set of lines, a sense of visual rhythm is established by the change in line spacing. Is there a physical response? Perhaps a small one, most

[55] Gary C. White, David Stuart, and Elyn Aviva. "Our Response to Music." *In Music in Our World: An Active-Listening Approach*. Boston: McGraw Hill, 2001.

likely with regard to how quickly your eyes pass over the lines. Now imagine the same technique applied to a corridor, in which the lines are painted vertically on the walls and across the floor and ceiling. As you pass through this space, the lines again get incrementally closer. The experience of walking through this corridor may arouse a feeling of excitement; it may physically entice you to move more quickly, it may even induce a rise in your heart rate. This example does not epitomize musical rhythm; however, it does demonstrate how visual rhythm in a space can evoke a physical response.

If form and space have the ability to evoke a human response, then a tangible link is drawn between music and architecture. The design of musical architecture should therefore utilize specific qualities of music to induce similar human responses.

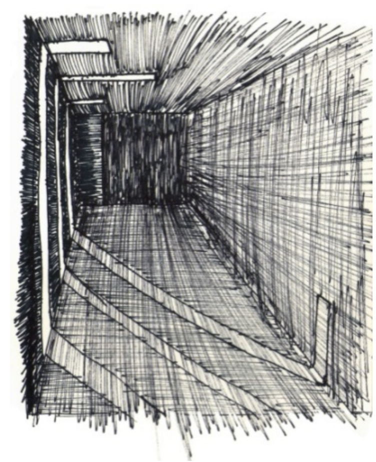
The 4th Dimension

One aspect that distinguishes music and architecture from many other creative mediums is its use of and its connection to the 4th dimension, the dimension of time. No other art forms are so heavily impacted by time. Johan Wolfgan von Goethe (1749-1832) stated, “I call architecture frozen music.” Architecture can be viewed as a static object; however, it is an art form that can only be experienced through time, just as the art of music. The sequence of events that take place in both forms are pertinent to the overall experience of the work at hand; without it, they would be mere glimpses of reality.

A reduced definition of music describes it as sounds that are ordered through time. Musical notation itself describes how musical pitches, or the absence thereof, are organized over time. Symbols are created to demarcate specific intervals of time; they indicate the note being played, when it is played, and for how long it should sound.

If architecture were to be viewed as piece of musical notation, what would indicate or control the element of time? The movement of our eyes as they pass over a piece of architecture could "read" the form in a musical sense. A mechanical device constructed to pass over the form could establish a sense of time.

The sun could also be engaged as a constant representation of change over time; the shadows it casts and the play of light moving throughout the day could express and exploit this 4th dimension. A needle could be set up, much like that of a sundial, and as its shadow passes over the architecture, music is performed. However, the process of the sun's movement throughout the day is far too slow to create an instant declaration of this concept. Furthermore, these ideas *only* engage the visual senses and relinquish the physical engagement of architecture.



The movement of people, on the other hand, creates a constant progression through time. The motion of an individual through a space can create the perception of events happening over time. The individual becomes a moving timeline playing the architecture at a tempo established by his or her own two feet. The awareness of this event can take place within the individual as he/she moves through the space, while simultaneously perceived by another individual watching him/her.

The element of time is a substantial force in the experience of both architecture and music. An adaption of the way music is organized over time to the way architecture is experienced through time is essential in replicating our auditory perception of music to our visual perception of space and form.

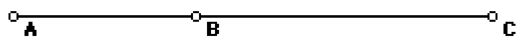
Phi & Fib

The Golden Mean is a ratio of proportion unparalleled in its discovery, use, and application within the physical universe. It is also referred to as the Golden Section, the Golden Ratio, and – in the times of the Renaissance – the *Divine Proportion*. The ratio itself is represented by the Greek symbol *Phi*, represented in the following forms: Φ or Ø. Phi is not to be confused with Pi (∏), which is the ratio of a circle's circumference to its diameter. Both Phi and Pi are irrational numbers, meaning their decimal degree continues infinitely. Phi is the "ratio of the line segments that result when a line is divided in one very special and unique way."[56] The ratio of Phi is formed when the proportion between the smaller line segment and the larger line segment is equal to the proportion between the larger line segment and the entire line.

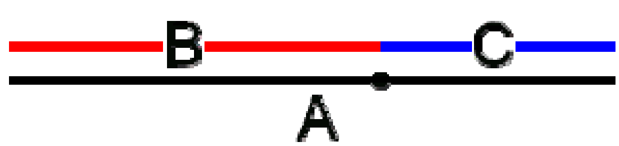
---

[56] PhiPoint Solutions, LLC. "Phi for Neo-phi-tes" GoldenNumber.net. http://goldennumber.net/neophite.htm (accessed April 6, 2011).

Phi is equal to [(1+ $\sqrt{5}$)/2] (1 plus the square root of 5 divided by 2), or [1.618033988749895...]. The following process depicted in Drexel University's *Math Forum: Ask Dr. Math FAQ,* describes how this numerical value was discovered:

> "Take a line segment and label its two endpoints A and C. Now put a point B between A and C so that the ratio of the short part of the segment (AB) to the long part (BC) equals the ratio of the long part (BC) to the entire segment (AC): 
>
>
> The ratio of the lengths of the two parts of this segment is the Golden Ratio. In an equation, we have AB/BC = BC/AC.
>
> Now we're ready for the definition of the Golden Ratio. The Golden Ratio is the ratio of BC to AB. If we set the value of AB to be 1, and use x to represent the length of BC, then 1/x = x/1+x
>
> If we solve this equation for x, we'll find that it is the value given above, (1+sqrt{5})/2, which is about 1.62."[57]

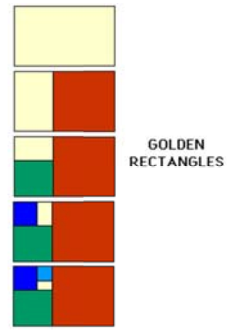
The image below depicts another representation of the Golden Ratio. The ratio between the lengths of line A and line B are the same as the ratio between the lengths of line B and line C.



[58]

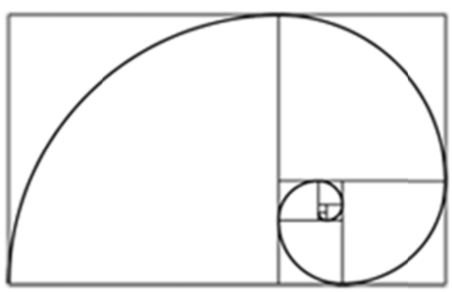
[57] Drexel University. "Math Forum: Ask Dr. Math FAQ: Golden Ratio, Fibonacci Sequence." The Math Forum. http://mathforum.org/dr.math/faq/faq.golden.ratio.html (accessed April 6, 2011).

A Golden Rectangle has a length and width defined by the Golden Ratio. That is to say, the rectangle's length is Phi times its width. If a perfect square were inscribed within this rectangle, the remaining area would represent another Golden Rectangle. Theoretically speaking, this process could be repeated infinitely, generating the fundamental principle behind the theory of fractals.

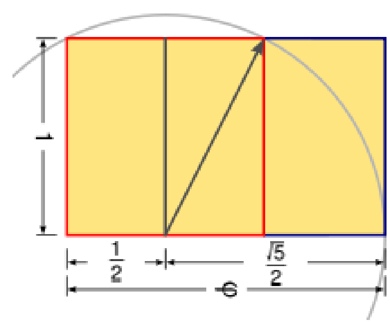


[59]

This sequence of division lays the foundation for the iconographic Golden Spiral (bottom-left). The Golden Spiral is created when opposing corners of the square divisions within the Golden Rectangle are connected through the expanding curve that reflects the ratio of Phi (1.618033988749895...).[60]


[61]

The Golden Spiral



[62]

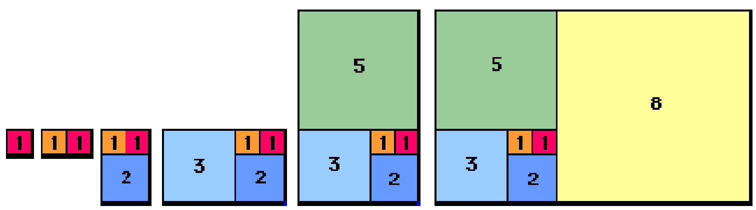
Golden Rectangle
Expanding Curve Formation

---

[58] PhiPoint Solutions, LLC. "Phi for Neo-phi-tes" GoldenNumber.net. http://goldennumber.net/neophite.htm (accessed April 6, 2011).
[59] PhiPoint Solutions, LLC. "Phi - The Golden Number." GoldenNumber.net. http://goldennumber.net/index.htm (accessed April 6, 2011).
[60] "Golden Ratio Media About Us ." Golden Ratio Media. http://goldenratiomedia.com (accessed April 6, 2011).
[61] "Golden Ratio Media About Us ." Golden Ratio Media. http://goldenratiomedia.com (accessed April 6, 2011).
[62] Heather McGougal. "Cabinet of Wonders: The Wonder of the Golden Proportions." Cabinet of Wonders. http://cabinet-of-wonders.blogspot.com/2007/09/wonder-of-golden-proportions.html (accessed April 7, 2011).

 [63]

The growth of the Golden Mean works in succession, where the next segment is equal to the sum of its previous two. This is the same principle that dictates the Fibonacci Sequence, a mathematical series invented by the Italian Mathematician Leonardo Fibonacci in the 12th century. The Fibonacci succession proceeds: 0, 1, 1, 2, 3, 5, 8, 13, 21, 34, and continues infinitely. As you advance through this succession, the ratio of one number to its predecessor progressively approaches the Golden Ratio. The Fibonacci Sequence can also be used to construct the Golden Rectangle (showcased below), evolving outward rather than dividing inwards.[64]



FIBONACCI SQUARES [65]

Numerous aspects of this progression can also be found in Western music theory. The eight pitches in a Diatonic Scale (typical scale in Western music) are referred to as scale degrees. The first scale degree (**1**) is known as the tonic, and resides as the

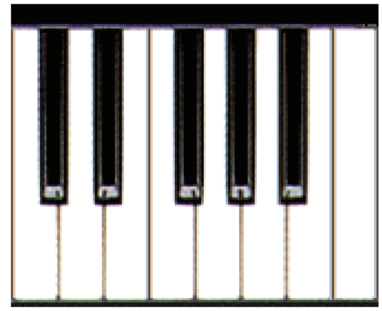
[63] PhiPoint Solutions, LLC. "The Devine Proportion and Life." GoldenNumber.net. http://goldennumber.net/index.htm (accessed April 6, 2011).

[64] Drexel University. "Math Forum: Ask Dr. Math FAQ: Golden Ratio, Fibonacci Sequence." The Math Forum. http://mathforum.org/dr.math/faq/faq.golden.ratio.html (accessed April 6, 2011).

[65] Drexel University. "Math Forum: Ask Dr. Math FAQ: Golden Ratio, Fibonacci Sequence." The Math Forum. http://mathforum.org/dr.math/faq/faq.golden.ratio.html (accessed April 6, 2011).

foundation of a scale or key. A *whole tone* is always **2** steps from any root note. For example, the pitch change from C to a D or G to A (within a given scale) is **1** whole step or **2** half steps; however, the pitch change from a B to C and from an E to F is only a half-step (also declared as a *semitone* or a *half tone*). The fundamental chord formation is a triad, which consists of the base note (**1**), the third note from the base note (**3**), and the fifth note from the base note (**5**). The first, third, and fifth scale degrees also play a fundamental role in all chord formations of that key. A major scale in any key is composed of **8** pitches and there are **13** pitches between any octave. The term "octave" is the Latin word for the number **8** referencing the eight whole tones in any major scale.

In a diatonic scale, the first, fourth, and fifth scale degrees play a fundamental role when creating harmonically organized music. Major chords constructed from these degrees are known as *primary chords,* dictated by their leading role in harmonic progressions. One reason these three chords are so powerful is that through their construction they touch every note in the scale. The first scale degree is referred to as the *tonic* or *keynote*, the fourth as the *sub-dominant*, and the fifth as the *dominant*. The dominant degree (**5**) is also the **8**th pitch of the **13** pitches that comprise the octave. Interestingly enough, eight divided by thirteen is .61538…, nearing the value of Phi at .61803… When analyzing the intervals between these primary notes, a striking relationship to the Golden Ratio is revealed. It is easier to visualize this relationship if we discuss the incidence within a specific key or scale. The key of C-Major will be used because none of the notes within the scale have sharps or flats. Refer to the image of the keyboard (right)[66] depicting a C through its octave. The primary notes in the key of C-Major are C (Tonic), F (Sub-dominant), and G (Dominant). Recall the principle of the Golden Section, where the ratio between the line segments (A) and (B) are equal to the ratio between the line segments (B) and (C). With regard to the intervals between the primary notes, C is to F as G is to C, whether you are moving up or down in the scale.[67]



In musical analysis, Roman numerals are used to represent chords built from different scale degrees (**I** through **VII**, then **I** again for the octave). Standard Roman numerals represent major chords, while lowercase letters in Roman numeral form represent minor chords. Therefore, **I** is to **IV** as **V** is to **I**. This relationship touches on two other immensely important concepts within Western music theory: the concepts of Cadence and Circle Progressions.

The concept of cadence in music is analogous to the pauses and breaks we make in spoken and written language, such as the descending pitch at the end of a spoken sentence: “The word cadence comes from the Latin word *cadere*, which means ‘to fall.’ Thus the cadence is a form of musical punctuation, similar to the period or comma in

[66] PhiPoint Solutions, LLC. "Music and the Fibonacci Series” GoldenNumber.net. http://goldennumber.net/music.htm (accessed April 6, 2011).
[67] PhiPoint Solutions, LLC. "Music and the Fibonacci Series” GoldenNumber.net. http://goldennumber.net/music.htm (accessed April 6, 2011).

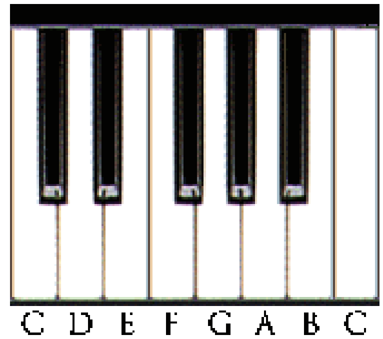
written language."[68] Merriam-Webster defines cadence as "a concluding and usually falling strain; *specifically***:** a musical chord sequence moving to a harmonic close or point of rest and giving the sense of harmonic completion;"[69] the reason musical cadence distinguishes a pause or ending is because the final pitch or chord resolves the one prior to it. That is to say it moves from a sound of dissonance (unstable) to a sound of consonance (final or stable), and because of that movement, we are able to rest; we feel that the piece has come to a resolution. It is interesting that music has such a strong effect on our emotive state of mind; if a song or melody did not resolve itself using cadence we would be left feeling uneasy, or dissatisfied. In some cases, this emotive quality is desired, and utilized to create interest and tension; however, in Western music theory, dissonance is never considered a proper ending to a musical piece.

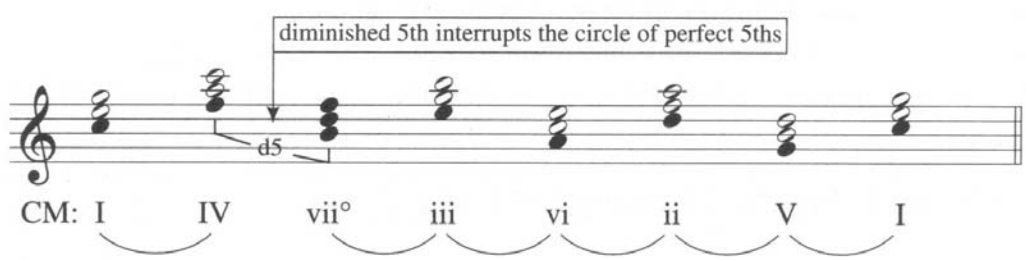
There are several types of musical cadence; these include phrygian, authentic, plagal, half, and deceptive cadences while being classified as final, interior, harmonic, melodic, perfect, or imperfect.[70] The most commonly used cadences are the authentic and plagal, with the authentic cadence creating the strongest sense of resolution. An authentic cadence moves from the dominant (**V** or $\mathbf{V^7}$) to the tonic or octave (**I**) (typically you would move down in pitch to the keynote), while the plagal cadence moves from the subdominant (**IV**) to the tonic (**I**).

---

[68] Gary C. White. "Introduction to Harmonizing and Composing." In *Music first!*. 5th ed. Boston: McGraw-Hill, 2007. 230.
[69] "Cadence." Dictionary and Thesaurus - Merriam-Webster Online. http://www.merriam-webster.com/dictionary/cadence (accessed April 11, 2011).
[70] George Thaddeus Jones. "Chord Choice." In *Music Theory*. New York: Barnes & Noble Books, 1974. 124-131.

Music theorist say that “the strongest harmonic progressions in tonal music are those consisting of major and minor triads [along with seventh chords built on these triads], whose roots are a perfect fifth [or fourth, depending on how you look at it] apart.”[71] Note the relationship between C and G on the image of the keyboard (above)[72]. These progressions are referred to as circle progressions, which are achieved by either descending a fifth or ascending a fourth. Remember, we are dealing with chords here, not singular pitches; thus, the movement from a chord built off G, to a chord built off C above or below the root G, would constitute a circle progression. The same relationship stands between a progression from D to G, E to A, F to B, and so on. The diagram below depicts a series of circle progressions in the key of C-Major. Note that some of the progressions have been written as ascending fourth progressions simply to keep the chords on the staff.

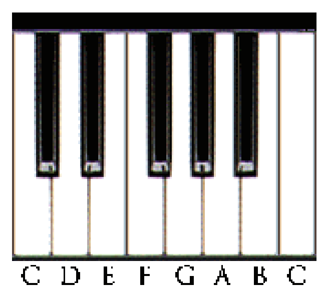




[73]

[71] Gary C. White. "The Harmonic System." In *Music first!* . 5th ed. Boston : McGraw-Hill, 2007. 204.
[72] PhiPoint Solutions, LLC. "Music and the Fibonacci Series” GoldenNumber.net. http://goldennumber.net/music.htm (accessed April 6, 2011).
[73] Gary C. White. "The Harmonic System." In *Music first!* . 5th ed. Boston : McGraw-Hill, 2007. 205.

A very common chord progression in Western popular music is a 1-4-5 or 1-4-5-1 progression (better notated as **I-IV-V**), along with a **I-V-vi-V** progression. You've heard these progressions a hundred times over even if you are unaware of them. They appear in classical music, blues, jazz, rock, hip-hop, and much more. Though the **I-V-vi-V** progression only has one circle progression (when you return to the tonic from the final fifth), the chords all have a strong harmonic link binding them together. For a brilliant example, expressing the wide use of the **I-V-vi-V** progression, look up the video, *Axis of Awesome – 4 Chords*. The **I-IV-V-I** progression serves as a perfect example of the circle progressions (up a fourth – down a fifth), and is probable cause for why it is so commonly used in musical movements. In C-Major this progression would go: C-F-G-C. This progression also ends with an authentic cadence, making it a circle progression.



Another connection to the Fibonacci numbers can be seen in the physical layout of the keyboard. Refer again to the image of the keyboard on the right.[74] There are **13** keys that comprise the octave from C to C above. There are **8** white keys and **5** black keys, where the black keys are separated into groups of **3** and **2**.[75]

The Fibonacci numbers can also be used to find key intervals defined by frequency ratios. Refer to the image below.

---

[74] PhiPoint Solutions, LLC. "Music and the Fibonacci Series" GoldenNumber.net. http://goldennumber.net/music.htm (accessed April 6, 2011).
[75] PhiPoint Solutions, LLC. "Music and the Fibonacci Series" GoldenNumber.net. http://goldennumber.net/music.htm (accessed April 6, 2011).

Fibonacci Ratio	Calculated Frequency	Tempered Frequency	Note in Scale	Musical Relationship	When A=432 *	Octave below	Octave above
1/1	440	440.00	A	Root	432	216	864
2/1	880	880.00	A	Octave	864	432	1728
2/3	293.33	293.66	D	Fourth	288	144	576
2/5	176	174.62	F	Aug Fifth	172.8	86.4	345.6
3/2	660	659.26	E	Fifth	648	324	1296
3/5	264	261.63	C	Minor Third	259.2	129.6	518.4
3/8	165	164.82	E	Fifth	162 (Phi)	81	324
5/2	1,100.00	1,108.72	C#	Third	1080	540	2160
5/3	733.33	740.00	F#	Sixth	720	360	1440
5/8	275	277.18	C#	Third	270	135	540
8/3	1,173.33	1,174.64	D	Fourth	1152	576	2304
8/5	704	698.46	F	Aug. Fifth	691.2	345.6	1382.4

[76]

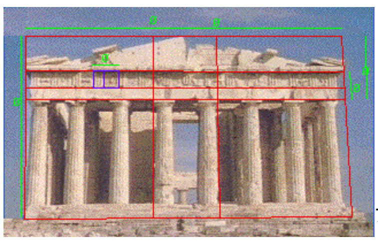
Many of the relationships examined above may appear coincidental, and easily dismissed as interesting conundrums; however, they are defined through natural phenomena, creating a "cosmic order" to both music and architecture. "Divine proportions" have been used extensively in arts of all mediums, drawing a strong connection between the order of music and the order of architecture.

The Golden Mean and the harmonic series are proportions defined by nature, and have in turn (to an extent) dictated our sense of harmony and consonance in both aural and visual fields. These facts can in no way be discounted; nonetheless, the use of the golden proportion in architecture is still only an allusive connection to music. We will strive to devise a more direct and definitive bond between the two creative forms of expression.

[76] PhiPoint Solutions, LLC. "Music and the Fibonacci Series" GoldenNumber.net. http://goldennumber.net/music.htm (accessed April 6, 2011).

Divine Proportion

Helen Gardner and Fred Kleiner, in *Gardner's Art Through the Ages*, state that, "To the Greek mind, proportion in architecture and sculpture was much the same as harmony in music, reflecting and embodying the cosmic order."[77] Analogous proportions were utilized in Roman temples, Gothic cathedrals, Renaissance revival architecture, Tibetan mandalas, Buddhist stupas, meditation paths, figures of the Chinese *I Ching*, and ancient architecture of many other cultures and civilizations across the globe.


78

79

80

This ideal of divine proportion and cosmic order has shaped both music and architecture throughout the ages. The proportion of Phi and the Fibonacci sequence defined the *Golden Section*. Derived from a natural phenomenon, this proportion appeals to our visual senses, and is often utilized as an organizational element in architecture and countless other visual arts. The *Harmonic Series* is derived from the

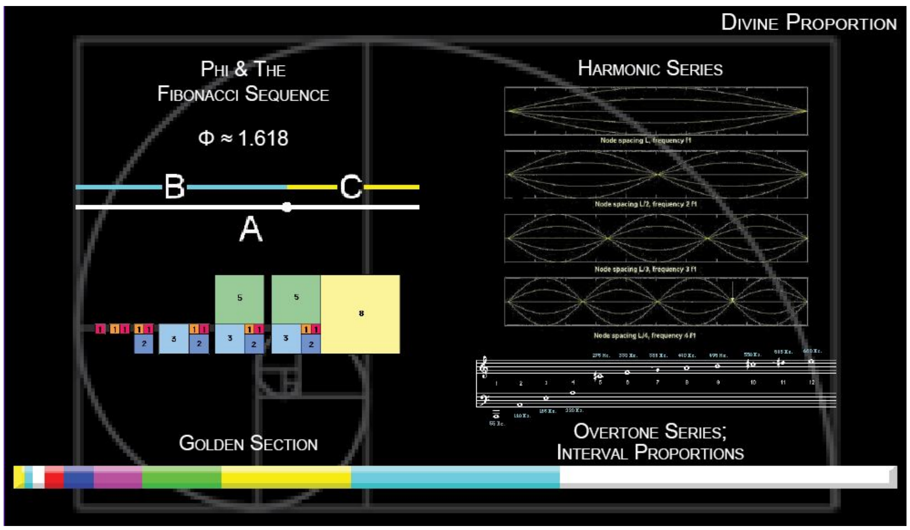
[77] Helen Gardner and Fred S. Kleiner. "Ancient Greece: Archaic Period." In *Gardner's Art Through the Ages: The Western Perspective*. 13th ed., Student ed. Boston, Mass.: Wadsworth Cengage Learning, 2010. 95.

[78] "The Golden Section." Math-Kitecture. http://www.math-kitecture.com/golden.htm (accessed April 20, 2011).

[79] Lundkvist, Annika. "Vajrayana Forms: The Mandala in the Architecture of Sacred Space." Vajrayana Forms. http://usvajrayana.blogspot.com/2010/04/mandala-in-architecture-of-sacred-space.html (accessed September 20, 2012).

[80] "Buddhist Architecture Design." this ARCHITECTURE. http://www.thisarchitecture.com/buddhist-architecture-design/ (accessed September 20, 2012).

phenomenon of natural divisions within a vibrating string or air column. These divisions defined the natural interval proportions between musical pitches. Appealing to our aural senses, these proportions became the foundation of musical order. The correlation of "divine proportion" and cosmic order to the creation of architecture and music is the primary comparison that has defined a relationship between the two creative fields.



The Golden Mean and the harmonic series have dictated our sense of harmony and consonance in both aural and visual fields of perception. The use of natural proportions within the fields of music and architecture draws a strong comparison between the two; however, it does not define architecture as a physical representation of music. This thesis aspired to define methods of translating musical concepts and musical structuring directly to the physical rendering of three-dimensional form. The use of the Golden Proportion offers insight to previous correlations between music and architecture; nonetheless, it stands as an allusive connection to music. Applying the actual interval proportions between musical pitches (like those found in the overtone series) to the proportions of an architectural composition would start to define the form or space as musical. In theory, the visual proportions of this space would then directly reflect the aural proportions of music, creating an experience that has a strong potential to communicate musical ideas. This thought process was a primary driving force for the explorations and conclusions of this thesis.

Case Studies

Steven Holl's, Stretto House

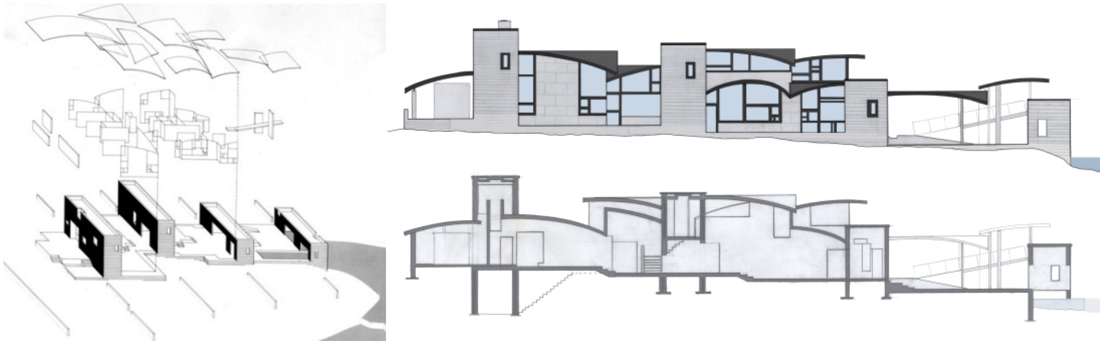
Born in 1947 in Bremerton, Washington, Steven Holl is portrayed as one of America's most significant architects, "recognized for his ability to blend space and light with great contextual sensitivity and to utilize the unique qualities of each project to create a concept-driven design."[81] These merits are paramount in Holl's conceptualization and design of the private residence, the Stretto House.

The Stretto House, designed and constructed from 1989 to 1991, is sited in Dallas, Texas, adjacent to a river flowing into three dammed ponds. The house is a delicately composed a piece of architecture that reflects the site's contextual qualities while physically representing characteristics found within Béla Bartók's musical composition "Music for Strings, Percussion and Celestra." Holl was particularly inspired by Bartók's use of the musical concept of *stretto*, "the close overlapping of two parts or voices, the second one entering before the first has completed its statement of the subject."[82]

---

[81] "Steven Holl Biography." Archinnovations: Online Architecture Magazine. http://www.archinnovations.com/featured-architects/architects-profile/steven-holl-biography/ (accessed March 21, 2011).

[82] "Stretto | Define Stretto at Dictionary.com." Dictionary.com. http://dictionary.reference.com/browse/stretto (accessed March 21, 2011).



[83]

The house is divided into four parts, reminiscent of the four distinct musical sections of Bartók’s composition. The dividers take form as solid concrete blocks, creating “spatial dams” between the overlapping flow of “aqueous space” throughout the house. The roof forms are curvilinear, and overlap each other as well as parts of the concrete blocks. “Music for Strings, Percussion and Celestra,” is composed entirely of percussion and stringed instruments creating a contrast between heavy and light elements. Holl expressed this relationship through the contrast of lightly-framed glass walls with the solidity of the roof forms and concrete masses, while simultaneously opposing curved roof forms with rectilinear walls.[84] Though somewhat superficially imposed, the Golden Ratio was applied to the mullion spacing of each glass façade, representing the natural order of visual harmony.

---

[83] "STRETTO HOUSE." STEVEN HOLL ARCHITECTS. http://www.stevenholl.com/project-detail.php?id=26&worldmap=true (accessed March 21, 2011).

[84] "STRETTO HOUSE." STEVEN HOLL ARCHITECTS. http://www.stevenholl.com/project-detail.php?id=26&worldmap=true (accessed March 21, 2011); Martin, Elizabeth. "Layered Relationships." In *Architecture as a translation of music*. New York: Princeton Architectural Press, 1994. 56-59.

[85]

The significant musical elements captured through the design of the Stretto House are the overall song form of Bartók's, "Music for Strings, Percussion and Celestra," the musical concept of stretto and the contrast of instrumentation (light and heavy). These elements are communicated through the visual observation of the complete composition, as well as the physical experience of passing through each space. The Stretto house exemplifies an application of musical concepts within architectural design, utilizing the combination of visual and spatial experience to perpetuate our perception of musical architecture.

Iannis Xenakis's, Sainte Marie de La Tourette

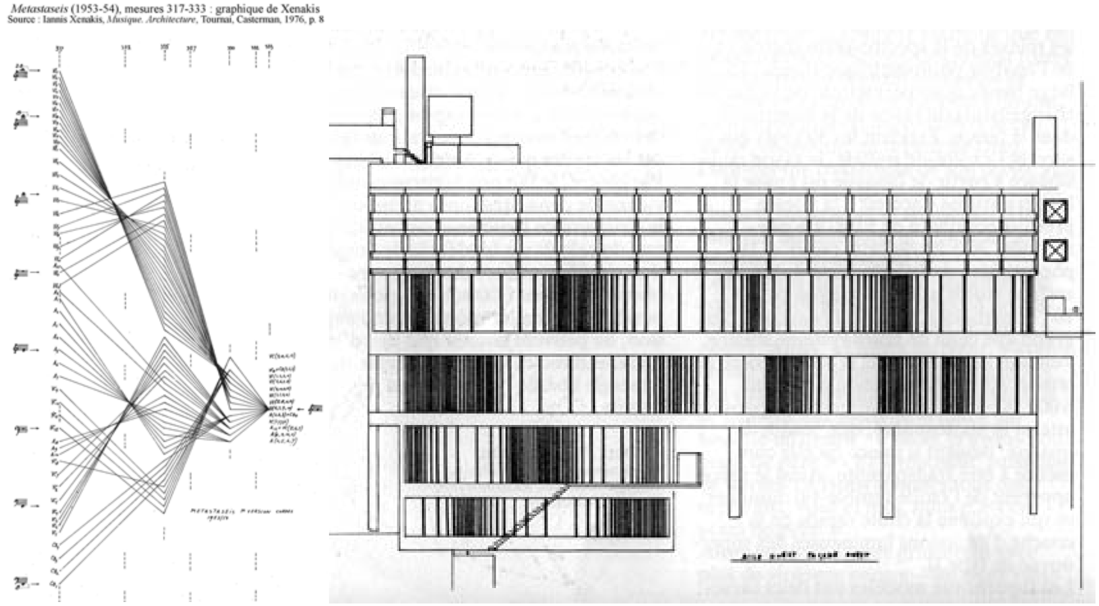
Iannis Xenakis came to Paris as a political refugee in 1947, where he began working as an engineer for architect Charles-Édouard Jeanneret (better known as Le Corbusier). His fascination for art and science led him to the conceptualization of overlapping mediums and cross-cultured philosophies. Today he is remembered as

[85] "STRETTO HOUSE." STEVEN HOLL ARCHITECTS. http://www.stevenholl.com/project-detail.php?id=26&worldmap=true (accessed March 21, 2011).

being a world-class engineer, mathematician, architect, and composer, excelling in all four of these esteemed professions, pushing the boundaries between them. Xenakis moved between disciplines and increased his overall perception and expression by using each to critique the other. In his lifetime, he was able to bring many of his ideas to realization, his most profound works embodying the intersections between music and architecture.

Working hand-in-hand with Le Corbusier, Xenakis's first attempt in relating music to architecture, applied the musical rhythm used in his composition "Metastaseis" (1953-1954) to the visual rhythm created by the "Undulating Glass Panes" of their architectural endeavor, Sainte Marie de La Tourette (1953-1960). While designing the compositions of "Metastaseis" and La Tourette, Xenakis was inspired by the techniques of glissandi (the rapid sliding up or down of the musical scale), chiaroscuros (the use of light and dark elements in a pictorial work), and the criterion of density in the number of events per unit of time.[86] The following images depict Xenakis's graphic representation of the last section in "Metastaseis" and the West elevation of La Tourette.

[86] Xenakis, Iannis, and Sharon E. Kanach. "The Le Corbusier Years." In *Music and architecture: architectural projects, texts, and realizations*. Hillsdale, NY: Pendragon Press, 2008. 41-47.



[87]

A stringed instrument can play five notes every second. In "Metastaseis," Xenakis implemented the use of 62 different string instruments, each sounding the intervals of the 12-tone chromatic scale in durations proportional to the relationship of each pitch. The graphic representation (upper-left) expresses the movement of each instrument by a diagonal line, where the ascending and descending structures represent a rise and fall in pitch. The vertical dashed lines highlight the areas of convergence (density) and separation (openness) between the pitches of each instrument. The pitch durations are based on an additive mathematical progression of stochastic calculations. This same technique was applied to the mullion spacing of La Tourette's fenestration, where the audible density of pitch has been applied to the visual density of window frames. This resulted in an intense display of varying rhythm across the horizontal

---

[87] "Xenakis as Architect." Iannis Xenakis. http://www.iannis-xenakis.org/xen/archi/real.html (accessed November 5, 2012).

façade of each floor. Vertically, Xenakis expressed the musical concept of harmonic counterpoint through the variable densities between each floor.[88]

Experienced through the visual perception of mullion spacing, the fenestration of La Tourette stands as a definitive expression of “Metastasies” complex rhythmic nature. This technique extends its communication of rhythm to the interior spaces, using sunlight to cast shadow upon the walls and floors; however, it remains as a two-dimensional composition and falls short in creating three-dimensional form and space spawned from music. Xenakis created many other physical expressions of music throughout his career, La Tourette was specifically analyzed for its expression of musical rhythm. For more insight on Xenakis’s work, study the Phillips Pavilion for the World’s Fair Expo '58 in Brussels, and his inventive “Polytopes,” that syndicate the use of light, space, music, form, and time.

---

[88] Xenakis, Iannis, and Sharon E. Kanach. "The Le Corbusier Years." In *Music and architecture: architectural projects, texts, and realizations*. Hillsdale, NY: Pendragon Press, 2008. 46.

Sound Wave Formations

Background

Building upon the work of Robert Hooke, Ernst Chladni, the late 19th century German physicist and musician, invented a technique that expressed the various ways a ridged surface vibrates. In 1787 Chladni's book, *Entdeckungen über die Theorie des Klanges*, or *Discoveries in the Theory of Sound*, was published, presenting the methods used in creating Chladni Plates. The technique consisted of running a bow across a lightly sand-coated sheet of metal until the material reached a state of resonance. The vibrations through the plate would shift the sand into the areas of no vibration, highlighting the nodal lines of the frequency's wavelength. The result created physical forms of frequency vibrations that are still used today in the design of acoustic instruments.[89]

In the 1960's, a Swiss scientist by the name of Hanz Jenny expanded on Chladni's methods by exploring the various ways frequencies affected a multitude of solids and liquids. Technological advances allowed Jenny to study how controlled frequencies altered the form of these materials, thus inventing the science of *Cymatics,* defined in his text *Cymatics: A Study of Wave Phenomena and Vibration*. Mainly concerned with the physics of this study, Jenny describes a Triadic Phenomenon, stating "Due to

[89] Torben, Rees. "Ernst Chladni: physicist, musician and musical instrument maker." Whipple Museum of the History of Science, University of Cambridge. http://www.hps.cam.ac.uk/whipple/explore/acoustics/ernstchladni/ (accessed October 8, 2012); "Ernst Florens Friedrich Chladni ." ILTweb. http://www.ilt.columbia.edu/projects/bluetelephone/html/chladni.html (accessed October 8, 2012).

vibration, we are confronted with a spectrum which reveals patterned, figurate formations at one pole and kinetic-dynamic processes at the other, the whole being generated and sustained by its essential periodicity."[90] After analyzing his experiments Jenny stated, "In every case there are formations, textures, and forms."[91]

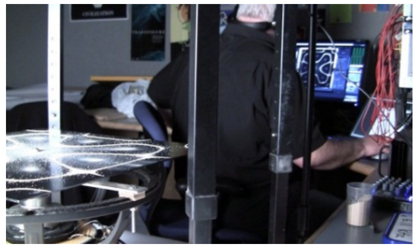
The brilliant minds of Hooke, Chladni, and Jenny led to future experiments, testing the ways in which specific pitch frequencies alter substances, thus creating physical formations. The following two projects beautifully capture the forms of sound through the manifestations of *Frequency Paintings* and *Sound Sculptures*.

Frequency Painting

Starting as a professional touring musician, artist Gary James Joynes transformed his career into the study of combined visual and aural stimuli. Joynes's newly released series, *Frequency Panting*, offers a multitude of audio-visual experiences produced through research conducted at the Banff Center form 2009-2011. The *12 Tones* installation of the series features twelve sculptural sound compositions, generated by passing pure tone frequencies through particulate sand, on Chladni Plates. The twelve selected displays came from nearly a year of testing and a process of elimination. Equipped with a speaker, each display emits the tone that generated its design. A sensor

[90] Jenny, Hans. "The BasicTriadic Phenomenon." In *Cymatics: A Study of Wave Phenomena and Vibration*. Newmarket, NH: MACROmedia, 2001. 121.
[91] IBID. 121-122.

installed at each piece triggers a random alteration in the volume of each pure tone, creating an ever-changing soundscape of auditory experience.[92]

Joynes utilized Chladni's technique and Jenny's cymatic principles to produce over 140 frequency generated forms. Their proportions are created through a purely natural phenomenon and represent the metaphysical order of nature. These "sacred geometries" are representative of Tibetan mandala diagrams, meditation paths, Buddhist temple design, Chinese *I Ching* depictions, and many other visual portrayals, demonstrating how this natural order can be used to formulate architectural design and define physical space.[93]

Are Joynes's formations truly musical? The forms generated through this study are expressions of pure tone frequencies. They represent the origins of musical sounds, and in some instances, convey the concept of harmony through the combination of multiple tones. Pure tones can vibrate at the same frequency as musical pitches; however, they are not typically pleasant to the ear, and they lack the tonal quality

---

[92] Joynes, Gary James. "12 TONES « GARY JAMES JOYNES | FREQUENCY PAINTING SERIES." The Website of Artist Gary James Joynes. http://www.clinkersound.com/frequency-painting/?page_id=66 (accessed October 7, 2012); Candler, David. "FREQUENCY PAINTING: 12 TONES." The Website of Artist Gary James Joynes. http://www.clinkersound.com/frequency-painting/?page_id=365 (accessed October 7, 2012).

[93] Smith, Greg J.. "Frequency Painting - Gary James Joynes Interview." Vague Terrain | Digital Art / Culture / Technology. http://vagueterrain.net/content/2011/01/frequency-painting-gary-james-joynes-interview (accessed October 7, 2012).

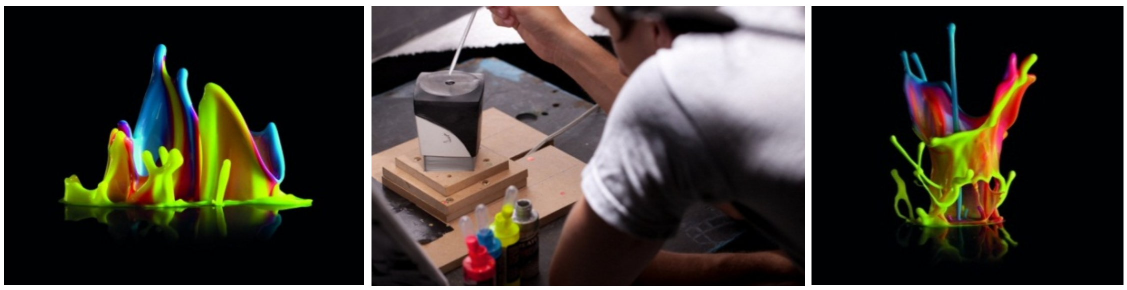
produced by instrumentation, known as *timbre.* Furthermore, these formations are snapshots of sounds, removing the element of time. The absence of presenting a procession of events falls short of truly representing musical structuring over time – a primary element of music.

Out of the twelve formations selected for the installation, none of them were created using the exact frequencies that are used in the Western scale of equal temperament. It is probable that these forms result from frequency intervals of *just intonation,* as defined by the *harmonic series*. This provokes a multitude of questions. Exactly which frequencies produce these elegant forms? Do octaves of a fundamental frequency produce the same form? Are these forms separated by a natural order (divine interval proportions)? Is there a fundamental frequency of nature from which all other formations are derived?

Joynes's frequency paintings offer a conclusive method of utilizing sound to create physical forms. Similar patterns of "sacred geometries" have been used to influence and shape the built environment throughout the ages; they stand as living proof of how natural order can be utilized to formulate architectural design.

Sound Sculptures

With the aspirations of reinvigorating the Canon Pixma brand, in the fall of 2010, the creative studio Detsu collaborated with biochemist/photographer Linden Glendhill, launching a project called "Bringing Colour to Life." The project involved capturing the forms that are created when sound is passed through a liquid. Latex was stretched over a small speaker and a few drops of paint were placed in the center of the membrane. The vibrations of a single tone played through the speaker caused the paint to jump into spectacular sculptures for a fraction of a second. High-definition cameras on a revolving platform were used to photograph the ephemeral life of the paint's physical form.[94]


[95]

Similar "sound sculptures" have been created by passing various frequencies through non-Newtonian liquids; the primary solution being a mixture of cornstarch and water. These forms were never captured in quite the same brilliance as in the "Bringing Colour to Life" project, but utilize a similar method to create form by means of sound. The following images are snapshots from videos that demonstrate this approach.


[96]

[94] Delana. "Paint + Sound = Sculpture?." WebUrbanist . http://weburbanist.com/2011/05/11/paint-sound-sculpture-wild-photos-videos-included/ (accessed October 7, 2012).
[95] DB, Nate. "dentsu: paint sound sculptures." designboom. http://www.designboom.com/weblog/cat/10/view/11774/dentsu-paint-sound-sculptures.html (accessed October 7, 2012).
[96] UltraSloMo. "Creature in the Sonic Liquid." YouTube. http://www.youtube.com/watch?v=Yw4qklgNIxI (accessed October 7, 2012).

Through experimentation during the *Bringing Colour to Life* collaboration, the project team found that “different instruments, frequencies, and volumes […] each had an effect on the formations.”[97] This is to say that timbre, pitch, and decibel levels all shaped the physical forms of the paint in a different manner. It is easy to comprehend how volume would alter the forms because an increase of intensity would amplify the sound waves, making them more extreme and powerful. An alteration in pitch changes the wavelength of the sound, thus changing the number of vibrations per second. Increasing the frequency of the tone shortens its wavelength, thus creating a faster vibration. The fact that timbre, or tonal quality of an instrument, alters the form of the paint is by far the most interesting aspect of the above statement.

Further investigation on how these three aspects of musical sound alter a malleable substance would be a marvelous way to decipher how specific musical pitches, and even the combination of musical pitches, can create physical forms. Advanced technology could aid in capturing these constructs and render them in a three-dimensional field. Articulation and design could then express these forms through the manifestation of an architectural piece, thus creating a reality of sound frozen in time.

This method of form-making utilizes the physical qualities of sound waves to shape the contours of matter. It stands as a definitive means of translating musical tones into a physical form; but are these forms truly musical? Would the vibrations of

---

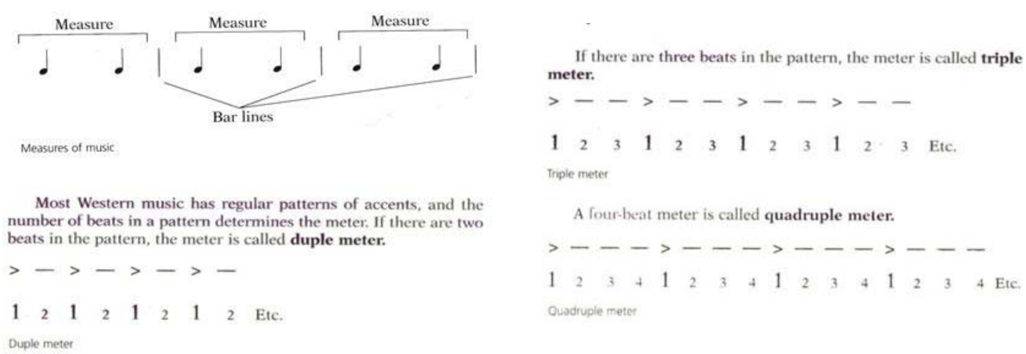
97 "Sound Sculptures | mcgarrybowen uk." mcgarrybowen london. http://www.mcgarrybowen.co.uk/blog/2010/09/28/sound-sculptures/ (accessed October 7, 2012).

pure tones or noise create similar forms? The only aspects that qualify them as musical are the notions that tonal quality, pitches within a musical range, and the combination of musical pitches alter their forms. They do not convey any ideas of musical concepts, nor do they represent musical order or the element of time. The method of passing sound through an adaptable substance stands alone as a single strand in the means of translating music into a physical form.

Explorations

Rhythmic Space

As noted before, the most common human reaction to music is in response to its rhythm. Rhythm is the primary structuring element in music; it creates order amongst musical sounds; where “beats are regular pulses that provide a framework that organizes music in time.”[98] A regular pattern of beats is referred to as meter. In Western musical notation, one component of an established pattern of beats is referred to as a measure, or a bar, and is divided by vertical lines, called bar lines. Beats can be accented or unaccented, which refers to the emphasis put on the beat. It is typical to accent the first beat of each measure.[99]



[100]

The images above depict how a constant beat is created and mapped physically as a representation of time. The beat can be seen as a steady tempo, one that is

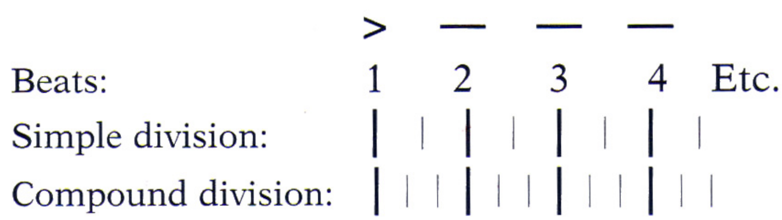
---

[98] Gary C. White. "Elements of Music: Rhythm." In *Music first!* 5th ed. Boston: McGraw-Hill, 2007. 21.

[99] Gary C. White, David Stuart, and Elyn Aviva. "Beat, Accent, and Tempo." *In Music in Our World: An Active-Listening Approach*. Boston: McGraw Hill, 2001.

[100] Gary C. White, David Stuart, and Elyn Aviva. "Meter." *In Music in Our World: An Active-Listening Approach*. Boston: McGraw Hill, 2001. 74-75.

constant in time. As an example think of your heartbeat: feel the rate of your heart as it pulses in a consistent manner. In music, there are many events that take place within a beat; these are known as divisions of the beat. Simple division refers to a beat that is divided into two equal parts. Compound division refers to a beat that is divided into three equal parts.[101]



Simple and compound division of a beat [102]

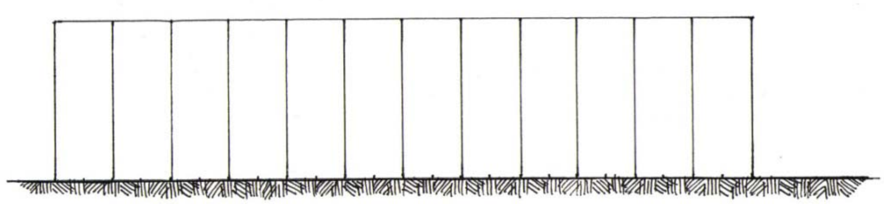
Musical notation already stands as a visual representation of musical mapping; we can see the patterns and relate to them. The same principles that govern the way music is ordered can also govern the way architecture is ordered, and in many cases already does. Anytime we see even spacing between architectural elements, we can sense an established rhythm, as in a row of columns on a Greek temple, or the even spacing of fenestration on a modern high-rise. This may have been an intentional action or just a result of structural engineering; regardless, when designing a piece of architecture that is intended to be musical, rhythm must be articulated with keen awareness.

---

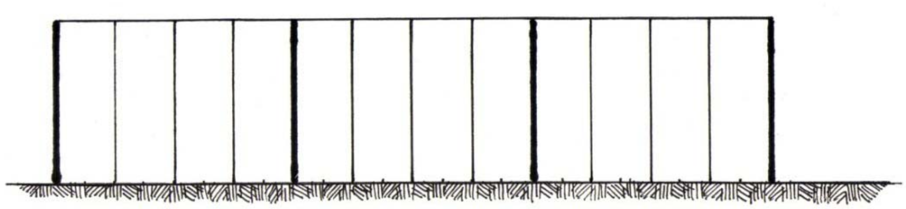
[101] Gary C. White, David Stuart, and Elyn Aviva. "Meter." *In Music in Our World: An Active-Listening Approach*. Boston: McGraw Hill, 2001.

[102] Gary C. White, David Stuart, and Elyn Aviva. "Meter." *In Music in Our World: An Active-Listening Approach*. Boston: McGraw Hill, 2001. 75.

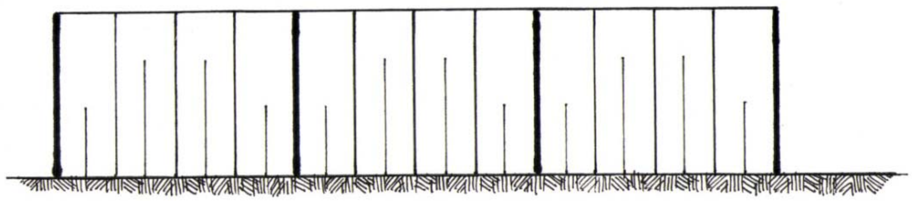
As the beats in a measure establish the framework for a rhythmic progression or a musical composition, it would be logical to apply this concept to the framework or structure of a building. First, an evenly spaced column grid should be constructed. We should then emphasis the down beat to establish a selected meter. This can be done by enhancing one column in an even pattern; the selected columns could be slightly thicker than the others, they could be taller than the others, or they could have a different material; the choice is entirely up to the designer. With this established, the distance between the selected columns would represent a musical measure. With a constant beat represented, we can then start adding secondary elements between the columns, or “beats” to establish divisions of the beat. The selected elements are again the choice of the designer – along with the selected division, either simple or compound. The following images depict this process on a building’s façade:



A given beat is established.



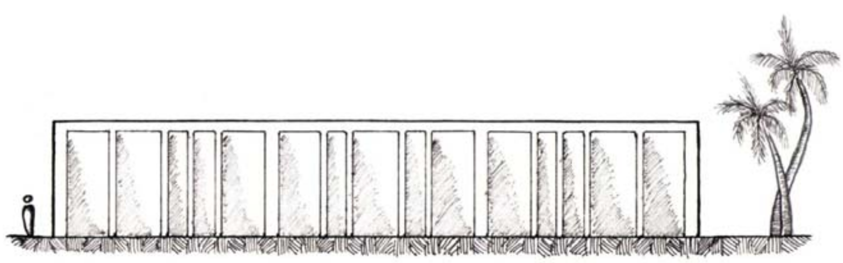
The first beat of a selected measure is accented.
In this example, a four beat measure has been selected.



The divisions of the beat are represented.
Simple division has been selected for this example,

It is important to note that the spacing of elements must remain even, just as a beat remains even. If the elements were not placed in an even sequencing, then the result would appear offbeat. Listening to music that does not follow a strict timing and constant beat can make the listener feel uneasy, and make the overall experience strenuous. A similar line can be drawn to architecture; thus, when creating “musical architecture” that is anatomically correct, a constant and steady beat is critical.

This is not to say that every beat and its division must be represented. If this were true in both music and architecture, the result would be quite sterile. We enjoy music and architecture because of the way it shifts and changes. Rhythm is more accurately defined as a pattern of elements or events taking place on and within a given beat. By selecting which beats are represented and which ones are not, a true rhythm begins to emerge. It is in this action that a designer may begin to perform as a true composer of architecture.



Example of true musical rhythm established in architecture.

Though literal in its translation, the Rhythmic Space exploration applies the conventions of Western musical rhythm to the placement of physical objects in space, creating a "musical" experience that appeals to our visual senses. Rhythmic order is conveyed by visually scanning the overall form, or by passing through the space and experiencing the physical procession of events.

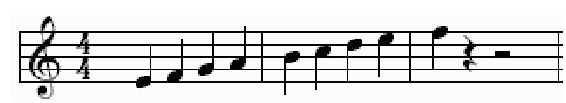
This study exemplifies the way rhythm is formulated in Western music theory, and utilizes a similar process to construct an architectural composition. Basic rules and parameters were defined to highlight how musical rhythm functions, primarily by establishing a regular or repetitive order. The predominant notion communicated through this study is that select elements of the form must establish a progressive pattern, and therefore create a sequence of events that convey the ideals of musical rhythm.

Musical rhythm is one of the easiest concepts to translate into three-dimensional form because it directly relates to our visual senses. Rhythm is one of the primary elements of music; however, it is only a framework by which musical sounds are ordered, and does not represent music as a whole. This exploration would therefore be strengthened by combining it with elements that represented the melodic aspects of music, such as the rise and fall of musical pitches. Furthermore, the method used in the Rhythmic Space exploration was only tested using a very simple rhythmic structure; utilizing rhythmic progressions of greater complexity would render a far more dynamic space.

Notation-Formation

Music notation is the written language of music, constructing a visual system of symbols that transcribe musical pitches and their occurrence in time, into a two-dimensional document. A musical composition can thus be written out in what is referred to as a musical score, or sheet music. Without expressing what every symbol in this written language represents, the two images below convey a general understanding of how the system is constructed. The most important observation to make is that the circular shapes with lines extending off their tops and bottoms (notes) represent specific pitches, dictated by their placement on the horizontal lines of the staff. The image on the bottom-right illustrates all of the musical notes on the treble clef: E, F, G, A, B, C, D, E, and F (left to right):

[103]



If sheet music stands as a two-dimensional illustration of music, then an extremely literal translation can be achieved through the simple reinterpretation of the notation itself. The following figures depict how this transformation could be perceived:

[103] Gardner Read. *Pictographic score notation: a compendium*. Westport, Conn.: Greenwood Press, 1998.

Figure 1

A segment of a songs primary melodic line, to which the following four representations are derived

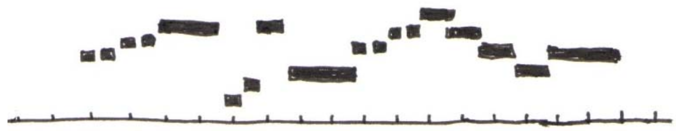


Figure 2

A two-dimensional representation depicting the relationship between each note of the melody, along with its duration

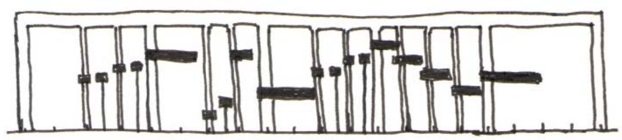
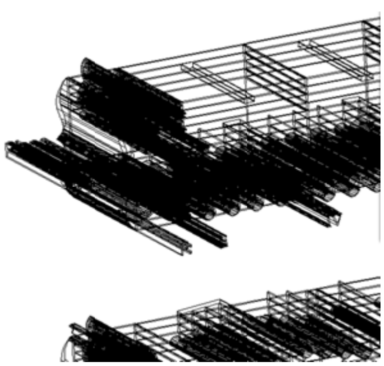
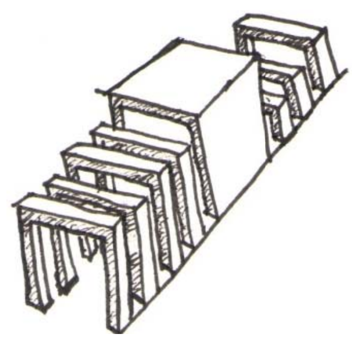


Figure 3

An application of the melodic extraction depicted in figure 2, combined with delineations of the rhythmic space exploration





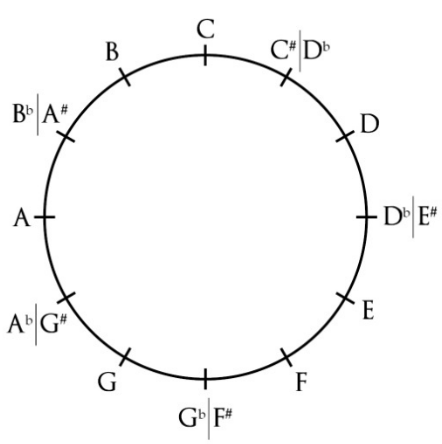
The Notation Formation study is also literal in its translation, and its results only convey some of the visual patterns and physical qualities that arise from music. Music notation resides as a two-dimensional representation of organized musical pitches. This exploration took that two-dimensional illustration and extrapolated it into three-dimensional forms. Several examples are given for different products of this method in form making.

The first method resulted in a scheme that appealed mainly to our visual senses. Though it can be experienced in three-dimensional space, it is more of an abstracted mural of musical notation. The final example extruded the abstracted notation in three dimensions. This created an overall form that fashioned an experience catering to the user's perception of objects in space.

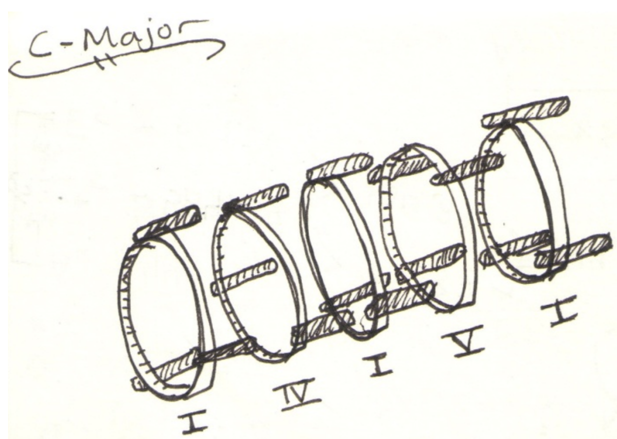
This exploration expanded on the Rhythmic Space study by incorporating both an expression of rhythm and an expression of melody. The placement of elements in a linear procession represented the rhythmic aspect of the music, the width of the elements represented the duration of the musical tones, and the rise and fall of the elements represented the melodies change in pitch. Though this exploration is literal, it captured two fundamental elements of music: rhythm and melody.

The Circle of Equal Temperament

The parameters of the Circle of Equal Temperament are governed by the doctrine of 12-tone harmony, which is in essence 12-tone equal temperament. This exploration takes shape by applying the principle and divisions of an octave to a circular layout. Because an octave is perceived as the same sound, and its note delineation is a replica of its fundamental, tonic, or keynote, it is perfectly logical that the scale would come full circle. A circle is divided into twelve equal segments, each node representing a single note of the Western 12-tone chromatic scale. The diagram on the bottom left depicts the device. The image on the bottom right illustrates an application of the device to an experiential corridor representing a chord progression of the primary cords in a C-Major scale.



THE CIRCLE OF EQUAL TEMPERAMENT



The Circle of Equal Temperament is another literal translation of music into a visual field; however, it is quite intuitive, and represents multiple layers of musical concepts. Dividing any shape, or even a line for that matter, into twelve equal parts, would have served the purpose of representing a Western chromatic scale. A circle was specifically chosen because it physically represents the return of the scale to its octave – a full circle of musical notes, coordinated with our perception of their wavelengths.

The Circle of Equal Temperament is not a method of form-making in and of its own. It serves as a platform by which many explorations can be derived, and it functions as a method of organizing elements in space, just as a scale or a musical staff organizes pitches of different musical notes. Though the scheme represents multiple layers of musical understanding, it still resides as a two-dimensional object, and lacks the ability to express a rise and fall in pitch. The example of the corridor uses The Circle of Equal Temperament to demonstrate a progression of the primary chords in a C-Major scale, while simultaneously expressing the interval proportion between the notes of each chord.

The Circle of Equal Temperament serves as a useful convention and a powerful expression of musical organization. Further investigation should test the various applications of this device, and decipher ways to represent the primary elements of music, such as rhythm, time, and a change in pitch.

Melodic Contour

Music was previously described as sound that is organized over time, and that musical notation stands as a two-dimensional representation of that musical order. This exploration examines the movements that occur within a musical composition and utilize notational techniques to inspire form making.

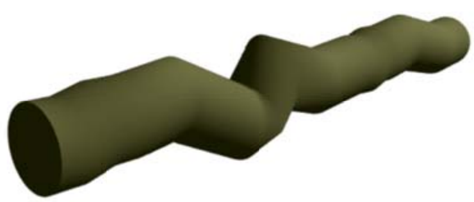
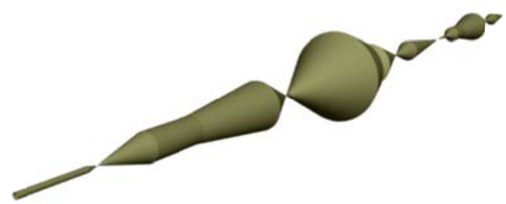
A melody or a melodic line is “a succession of tones that create a coherent musical impression.”[104] The melody is typically the most prominent musical element in a piece and is commonly the component of a composition that we remember when we think of a tune. It is the musical element that we personally identify with, and forms the causative constituent of the music’s emotive quality. Think of your favorite song and hum it aloud; the tones you are humming most likely construct the main melodic line of the song.

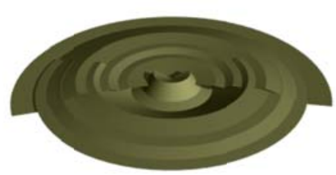
A melodic contour is a physical line drawn above a musical score that depicts the rise and fall of pitches in a melodic line. It is typically used in musical analysis to investigate ascending and descending structures within a song. Many early ethnomusicologists used the melodic contour as a means of analyzing and notating music of other cultures, because the wide variety of pitches used in their melodic schemes, did not fall within the twelve-tone scales of Western music. Utilizing this method, the researchers could notate subtle variations and inflections between musical tones.

[104] Gary C. White. "Glossary." In *Music first!* 5th ed. Boston: McGraw-Hill, 2007. 317.

The rise and fall of musical notes, as depicted in the notation above, are intuitive, as they correspond to a physical rise and fall of the song’s musical pitches. The melodic contour is drawn above the main melodic line as a representation of the transitions between the musical tones. The melodic line being analyzed is known as a *phrase*, the “smallest complete musical thought”[105] in the composition. A phrase is typically repeated with minor variations throughout a composition.

The melodic contour’s two-dimensional representation can be utilized in various ways to create three-dimensional forms in space. The following images illustrate some of the multiple operations possible in this transformation.


105 Gary C. White. "Introduction to Harmonizing and Composing." In *Music first!* 5th ed. Boston: McGraw-Hill, 2007. 228.

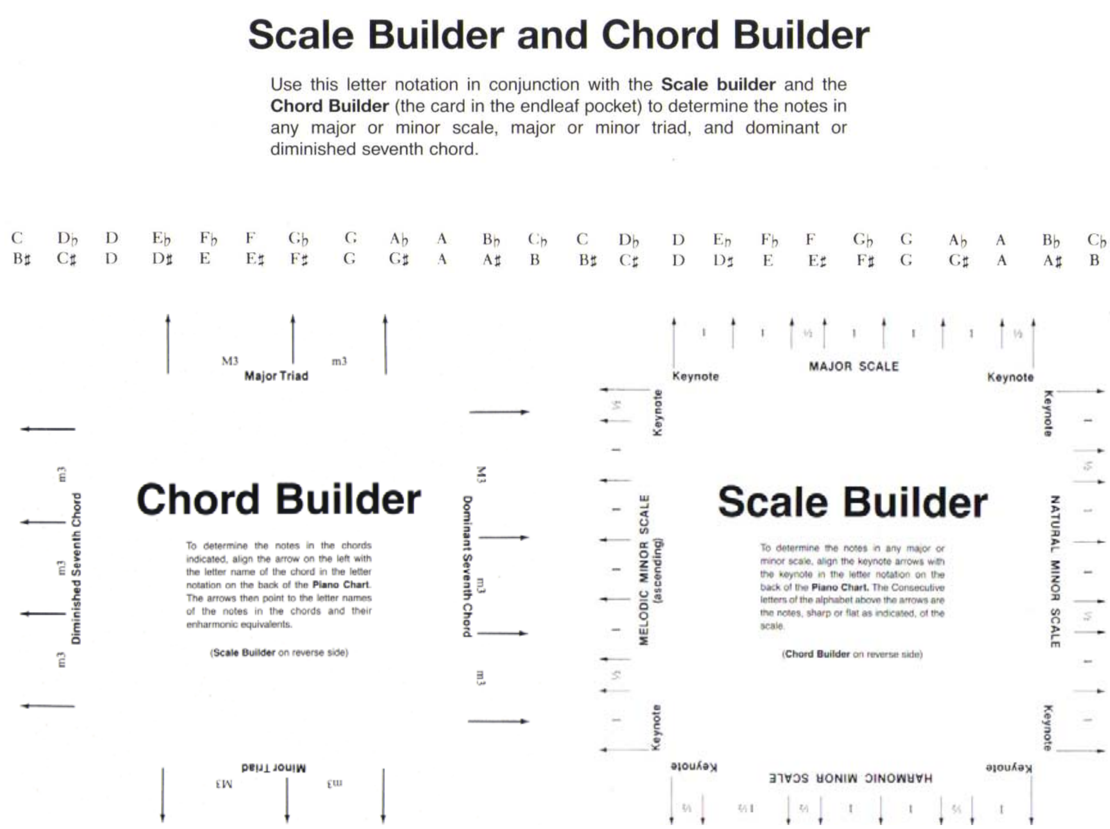
n notes

There countless ways the melodic contour can be applied to the creation of three-dimensional form. In a sense, this allocation of the melodic contour is analogous to that of the parti-diagram in architectural works. A parti-diagram is an initial sketch linking imagination to conception, and symbolically represents the concept of a design. It can be used to represent relationships between elements and spaces, order programmatic data, or express an overall form. In a similar fashion, the melodic contour has been used as a parti-diagram for musically-inspired forms in space.

Derived from a notational technique, the "Melodic Contour" exploration created a number of interesting forms that represented various musical elements. They convey a sense of rhythm and a change in pitch over time; however, their application to an overall form is somewhat arbitrary in relevance. Furthermore, the melodic contour is a mere illustration of the notation and does not directly reflect the actual change and duration of each melodic pitch. This convention served as a starting point that lead to the realization of the "Melodic Experience."

The Building-Block Theory

This exploration was inspired by the interactive “Scale Builder and Chord Builder” chart found in the text, *Music first!* 5th ed. by Gary C. White. The scale and chord builder components can be overlaid the on the scale and chord builder chart to verify which notes reside in the corresponding scale or chord. This is an exceedingly useful tool in determining the constituents of chords, intervals, and scales. In addition, the chart provides a visual reference, communicating a graphic understanding of the relationships between notes in different scales and chords. In turn, the user gains an added perspective on these relationships, and improved awareness of the construction within Western music. (Images are not to scale and cannot determine scales or chords)



The idea emerged that different musical notes could be represented through a variety of forms, elements, or shapes. In turn, they could then be combined to create varying, "Chord-Forms," or "Scale-Forms." The original idea was to select varying architectural components, such as columns, beams, walls, trusses, platforms, etc. As the application of these elements to specific musical pitches seemed arbitrary, a quest for matter derived from the pitches themselves commenced.

A musical tone (as previously discussed in the theory section) is defined by three main factors: frequency, wavelength, and intensity. Intensity levels are not definitive; the decibel level can easily be increased by turning up the volume, playing harder (acoustic instruments), or amplifying an instrument. Thus, the two definitive numbers defining pitch are frequency and wavelength.

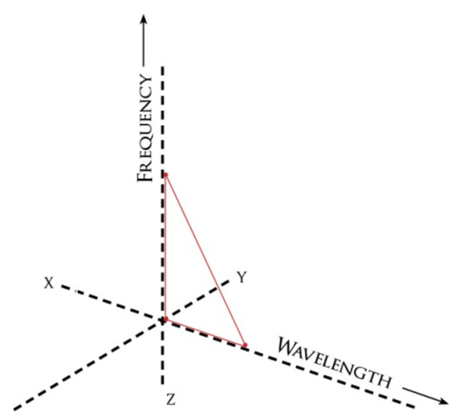
Wavelength is a unit of length typically measured in centimeters, whereas frequency is a measure of vibrations per second, not a measure of length. However, there is a proportional relationship between frequency and wavelength, therefore, if their typical units of measure are applied to the same unit of length, their proportional relationship remains intact regardless of scale.

The frequencies defined by Western equal temperament were used in this exploration. The following graph depicts a majority of the frequencies and wavelengths for pitches produced by Western instruments.

	Note	Frequency (Hz)	Wavelength (cm)		Note	Frequency (Hz)	Wavelength (cm)		Note	Frequency (Hz)	Wavelength (cm)
1	C_0	16.35	2100	**35**	$A^{\#}_2/B^b_2$	116.54	296	**69**	$G^{\#}_5/A^b_5$	830.61	41.5
2	$C^{\#}_0/D^b_0$	17.32	1990	**36**	B_2	123.47	279	**70**	A_5	880	39.2
3	D_0	18.35	1870	**37**	C_3	130.81	264	**71**	$A^{\#}_5/B^b_5$	932.33	37
4	$D^{\#}_0/E^b_0$	19.45	1770	**38**	$C^{\#}_3/D^b_3$	138.59	249	**72**	B_5	987.77	34.9
5	E_0	20.6	1670	**39**	D_3	146.83	235	**73**	C_6	1046.5	33
6	F_0	21.83	1580	**40**	$D^{\#}_3/E^b_3$	155.56	222	**74**	$C^{\#}_6/D^b_6$	1108.73	31.1
7	$F^{\#}_0/G^b_0$	23.12	1490	**41**	E_3	164.81	209	**75**	D_6	1174.66	29.4
8	G_0	24.5	1400	**42**	F_3	174.61	198	**76**	$D^{\#}_6/E^b_6$	1244.51	27.7
9	$G^{\#}_0/A^b_0$	25.96	1320	**43**	$F^{\#}_3/G^b_3$	185	186	**77**	E_6	1318.51	26.2
10	A_0	27.5	1250	**44**	G_3	196	176	**78**	F_6	1396.91	24.7
11	$A^{\#}_0/B^b_0$	29.14	1180	**45**	$G^{\#}_3/A^b_3$	207.65	166	**79**	$F^{\#}_6/G^b_6$	1479.98	23.3
12	B_0	30.87	1110	**46**	A_3	220	157	**80**	G_6	1567.98	22
13	C_1	32.7	1050	**47**	$A^{\#}_3/B^b_3$	233.08	148	**81**	$G^{\#}_6/A^b_6$	1661.22	20.8
14	$C^{\#}_1/D^b_1$	34.65	996	**48**	B_3	246.94	140	**82**	A_6	1760	19.6
15	D_1	36.71	940	**49**	C_4	261.63	132	**83**	$A^{\#}_6/B^b_6$	1864.66	18.5
16	$D^{\#}_1/E^b_1$	38.89	887	**50**	$C^{\#}_4/D^b_4$	277.18	124	**84**	B_6	1975.53	17.5
17	E_1	41.2	837	**51**	D_4	293.66	117	**85**	C_7	2093	16.5
18	F_1	43.65	790	**52**	$D^{\#}_4/E^b_4$	311.13	111	**86**	$C^{\#}_7/D^b_7$	2217.46	15.6
19	$F^{\#}_1/G^b_1$	46.25	746	**53**	E_4	329.63	105	**87**	D_7	2349.32	14.7
20	G_1	49	704	**54**	F_4	349.23	98.8	**88**	$D^{\#}_7/E^b_7$	2489.02	13.9
21	$G^{\#}_1/A^b_1$	51.91	665	**55**	$F^{\#}_4/G^b_4$	369.99	93.2	**89**	E_7	2637.02	13.1
22	A_1	55	627	**56**	G_4	392	88	**90**	F_7	2793.83	12.3
23	$A^{\#}_1/B^b_1$	58.27	592	**57**	$G^{\#}_4/A^b_4$	415.3	83.1	**91**	$F^{\#}_7/G^b_7$	2959.96	11.7
24	B_1	61.74	559	**58**	A_4	440	78.4	**92**	G_7	3135.96	11
25	C_2	65.41	527	**59**	$A^{\#}_4/B^b_4$	466.16	74	**93**	$G^{\#}_7/A^b_7$	3322.44	10.4
26	$C^{\#}_2/D^b_2$	69.3	498	**60**	B_4	493.88	69.9	**94**	A_7	3520	9.8
27	D_2	73.42	470	**61**	C_5	523.25	65.9	**95**	$A^{\#}_7/B^b_7$	3729.31	9.3
28	$D^{\#}_2/E^b_2$	77.78	444	**62**	$C^{\#}_5/D^b_5$	554.37	62.2	**96**	B_7	3951.07	8.7
29	E_2	82.41	419	**63**	D_5	587.33	58.7	**97**	C_8	4186.01	8.2
30	F_2	87.31	395	**64**	$D^{\#}_5/E^b_5$	622.25	55.4	**98**	$C^{\#}_8/D^b_8$	4434.92	7.8
31	$F^{\#}_2/G^b_2$	92.5	373	**65**	E_5	659.26	52.3	**99**	D_8	4698.64	7.3
32	G_2	98	352	**66**	F_5	698.46	49.4	**100**	$D^{\#}_8/E^b_8$	4978.03	6.9
33	$G^{\#}_2/A^b_2$	103.83	332	**67**	$F^{\#}_5/G^b_5$	739.99	46.6				
34	A_2	110	314	**68**	G_5	783.99	44				

[106]

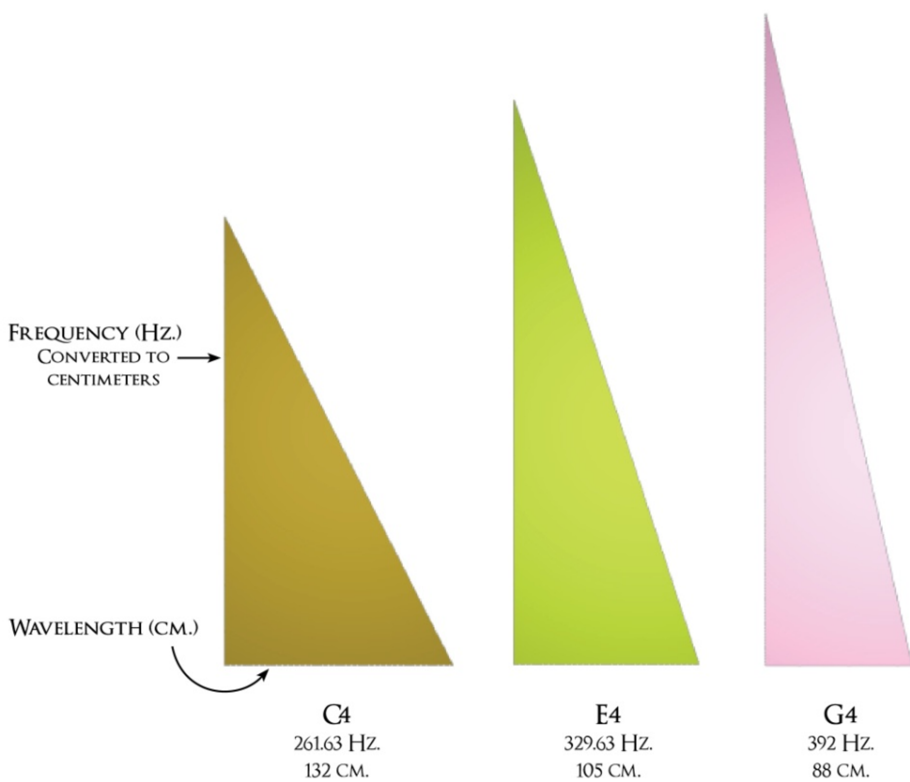
The numbers for each pitch were plotted on a coordinate system. The two points and their origins were then connected to create a triangular shape, a shape that varies with its specificity to pitch. The image to the right illustrates this process.



106 Bryan H. Suits. "Physics of Music - Notes." Michigan Technological University - Department of Physics. http://www.phy.mtu.edu/~suits/Physicsofmusic.html (accessed March 2, 2011).

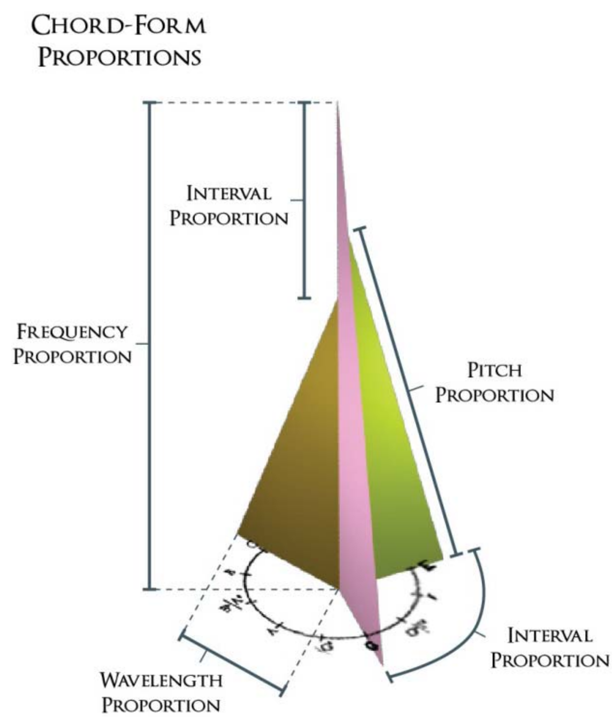
With a specific shape representing each musical pitch, they could then be combined the way musical pitches are combined to create chords.

The first trial constructed the most common chord in Western tonal music, the C-Major triad rooted on Middle-C. Middle-C is the C below our Western standard base pitch, A-440. In the graph above, Middle-C is referred to as C4. The C-Major triad is comprised of the following notes: C4-E4-G4. The image below depicts the three shapes created for these musical pitches. Both the frequency and the wavelength have been plotted at a standard distance unit to ensure that the relationships between frequency, wavelength, and each pitch are proportionate. In a sense, a new musical notation system has been created; accordingly, these shapes are referred to as "Shape-notes."



There are numerous ways in which these shapes can be arranged; however, an organization that corresponds with the relationship between each pitches was the most logical assessment. As such, the interval ratios between each pitch were used to define the liaison between the shape-notes. This can be achieved in a linear fashion (direction is at the discretion of the designer), or through a radial arrangement. For the following example, a radial distribution akin to the “Circle of Equal Temperament” was executed. The following graph (bottom-left)[107] depicts the ratios used to find intervals in both the just scale and that of equal temperament. The diagram on bottom-right depicts the shape-notes placed in their respective locations and all of the proportions a chord-form represents. In this instance, they are centered on their origin; however, they could be shifted at any distance from this center point and maintain their radial interval relationship.

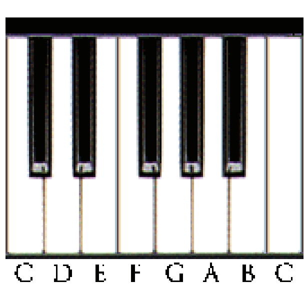
Interval	Ratio to Fundamental Just Scale	Ratio to Fundamental Equal Temperament
Unison	1	1
Minor Second	25/24 = 1.0417	1.05946
Major Second	9/8 = 1.1250	1.12246
Minor Third	6/5 = 1.2000	1.18921
Major Third	5/4 = 1.2500	1.25992
Fourth	4/3 = 1.3333	1.33483
Diminished Fifth	45/32 = 1.4063	1.41421
Fifth	3/2 = 1.5000	1.49831
Minor Sixth	8/5 = 1.6000	1.5874
Major Sixth	5/3 = 1.6667	1.68179
Minor Seventh	9/5 = 1.8000	1.7818
Major Seventh	15/8 = 1.8750	1.88775
Octave	2	2

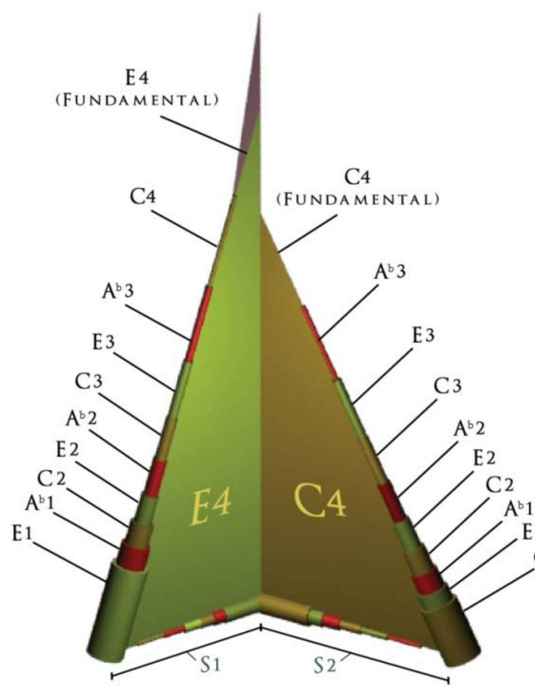


[107] Bryan H. Suits. "Physics of Music - Notes." Michigan Technological University - Department of Physics. http://www.phy.mtu.edu/~suits/Physicsofmusic.html (accessed March 2, 2011).

These shape-note layouts can be overlaid with a skin to create a solid form (right); however, this would hide some of the relationships that express their formal layout. In turn, a transparent skin or a glass façade could be used to wrap the form. Arising from the parameters that shaped these forms, they are referred to as 'chord-forms.'

On an attempt to achieve a greater connection to musical order, the adjacent segments of the shape-notes were divided into smaller segments, by the interval ratio that defines the relationship between each pitch/shape-note. This is the same principle that dictates the interval relationship in the division of a string. The fundamental frequency of the string is divided by the interval ratio to determine the frequency of the corresponding interval. In the following example, the specific segments (inner segments) that represent the note's frequency were not divided (the shapes could be rearranged to allow for this); nonetheless, because we are dealing with proportion, all segments of each "Shape-Note" stands as a physical representation of a specific pitch. As such, this theory can be applied to any segment of the "Shape-Notes." Since these "Shape-Notes" were constructed using the parameters of equal temperament, the corresponding interval ratios were used for the divisions. The diagram on the following page illustrates these interval divisions. The note-labels along the left and right sides of the diagram correspond to the full length of the segments they touch (from the base of the form to the visible part the ledger touches) and are numbered in accordance with our frequency-wavelength chart. The “Shape-Notes” illustrated are the E4 (left – green) and the C4 (right – tan). The interval segments have been accentuated to make them visible, and are color-coordinated with the notes they represent. The interval relationship between the two shape-notes is a major 3^{rd} (M3). Consequently, the fundamental lengths of the segments have been sequentially attuned by the equal temperament ratio of 1 : 1.25992 (divided by 1.25992 in a *sequence*). The shape-note of E4 (bottom-left – in green), will be used to explain how these intervals are achieved (the keyboard to the right is supplemented as a reference for the note and interval relationships). A M3 down from E is a C; in turn, the first segment in our sequential division represents a C in relation to the fundamental length (E). A M3 down from C is A^b; thus, our second segment represents an A^b in relation to the C-segment, and an augmented fifth interval in relation to our fundamental (E). The nuances of enharmonic equivalents are now revealed, with regard to proper classification of interval



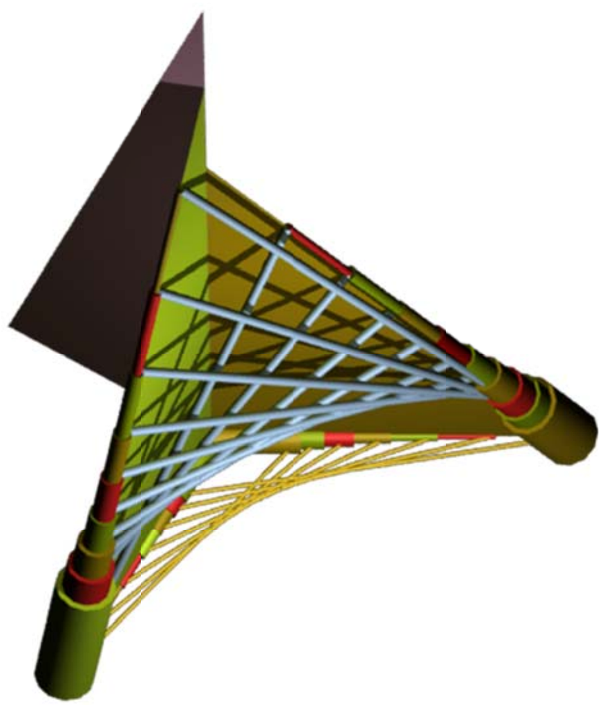


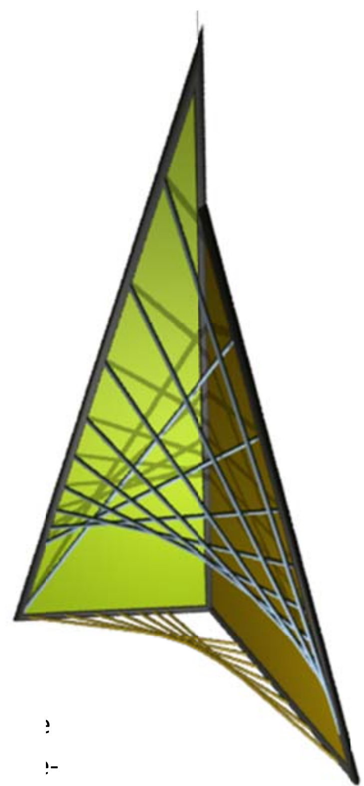
RELATIVE
INTERVAL DIVISIONS

S1 IS TO E4 · AS · S2 IS TO C4
THIS RELATIONSHIP STANDS TRUE BETWEEN ALL CORRESPONDING INTERVALS AND THEIR FUNDAMENTAL SEGMENTS

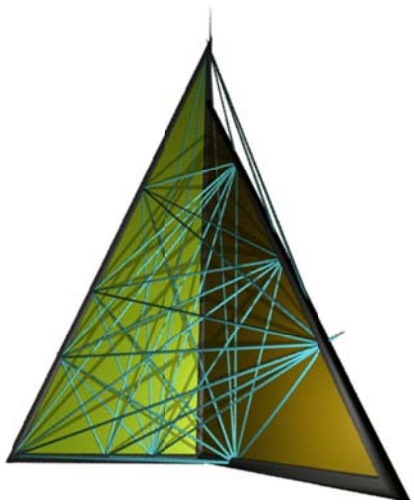
relationships. A M3 from our last segment, A^b, arrives at the octave of the fundamental, E4. Technically, this interval (down a M3 from A^b) should be identified as an F^b, because it was transpired from A^b (this is simply musical etiquette). Nevertheless, its relationship to the fundamental resides as an octave; as such, it will be referred to as an E3. This process was continued through three octaves of the fundamental segment, E4.

With the adjacent segments divided into corresponding intervals, the interval nodes can then be connected in various ways. Random connections can be implored to achieve a "desired" appearance (designer's opinion of consonance), or segments can be drawn that further exemplify musical concepts. The images below depict some of these relations.

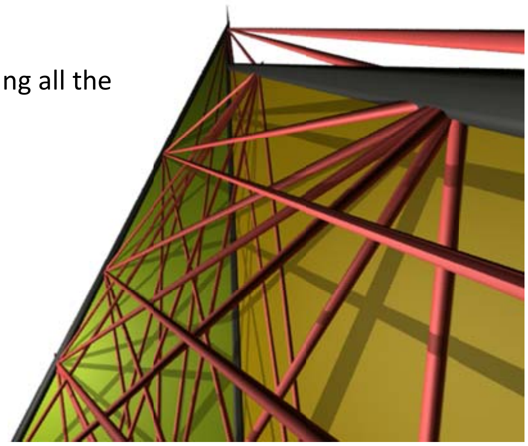




es



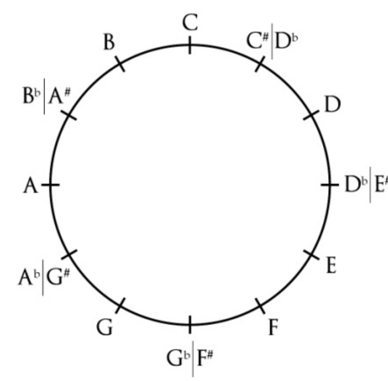
ng all the



There are countless options to explore, and further testing could determine if the segments connecting key intervals have any further significance (i.e.: the actual length of the segments correlate with the intervals they connect). Perhaps the segments connecting the interval divisions could utilize the “Circle of Equal Temperament,” or some other musical property to take on a curvilinear form rather than a straight line.

Getting even more technical, the division of the fundamental segments (adjacent edges of the shape-notes) could be divided by an interval ratio defined by the movement from one note to the other. If each relationship is addressed as a forward progression (up in pitch), then the interval from one to the other is no longer the same. The interval from C to the E would remain a M3, however, the interval from the E to the C would become a major 6^{th} (M6). As such, the segments drawn between the two would have exclusive origins and destinations.

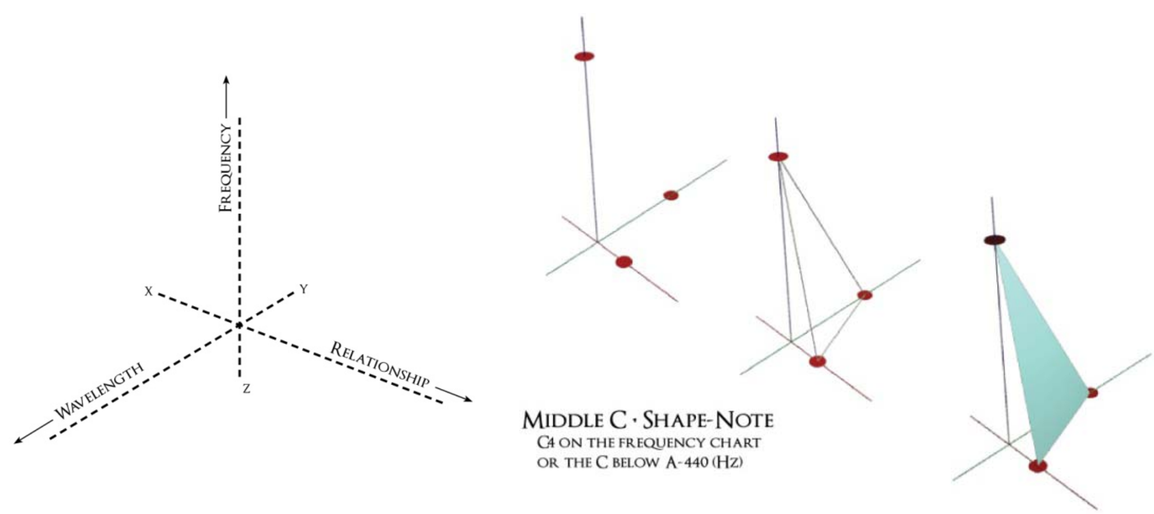
A dilemma is encountered here. The “Circle of Equal Temperament,” is not a real musical construct; it is one that has been developed through these explorations. As such, it could reside as a stationary blueprint by which interpolations are ordered; however, it bears a striking resemblance to the circle of fifths, which works in a progressive manner. To move clockwise through the progression we are moving up in pitch, and vice versa, to move counterclockwise is to move down in pitch. You can think of this on the keyboard – clockwise moving to the right (up in pitch), and counterclockwise moving to the left (down in pitch). The “Circle of Equal Temperament,” should follow this same principle; if not only for the simple fact that the notes it dictates are laid out in a clockwise progression.



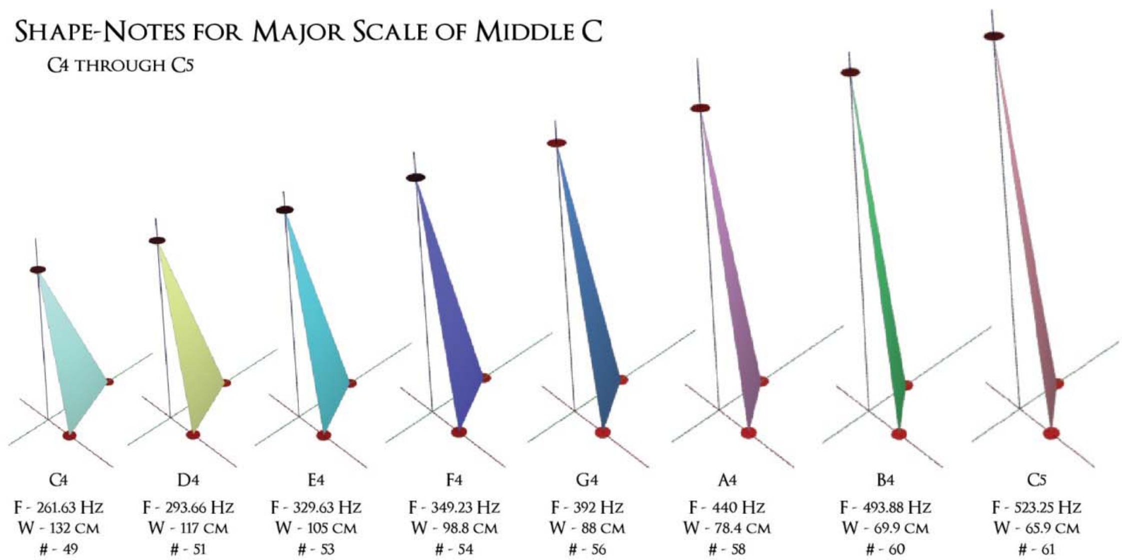
THE CIRCLE OF EQUAL TEMPERAMENT

This principle dictates a definitive way in which this system can be utilized. It would not be appropriate to connect the shape-notes in a direction that did not directly correlate with the pitches that define their interval. The system thus becomes far more complex. For instance, let us address the chord-form previously created, C4-E4-G4. The interval between the C4 and the G4 is a perfect 5^{th}. We could have divided the adjacent segments by the interval ratio that defined their relationship and connected them accordingly. However, the acute angle in their standing relationship – whether you move clockwise (up in pitch) from G to C, or counterclockwise (down in pitch) from C to G – represents a perfect 4^{th}, not a perfect 5^{th}. Furthermore, our shape-notes are pitch specific, which means there is only one definite relationship between them; a perfect fifth and the obtuse angle of their standing positions on the "Circle of Equal Temperament," This connection was not modeled; however, the constituents are in place for its formal design.

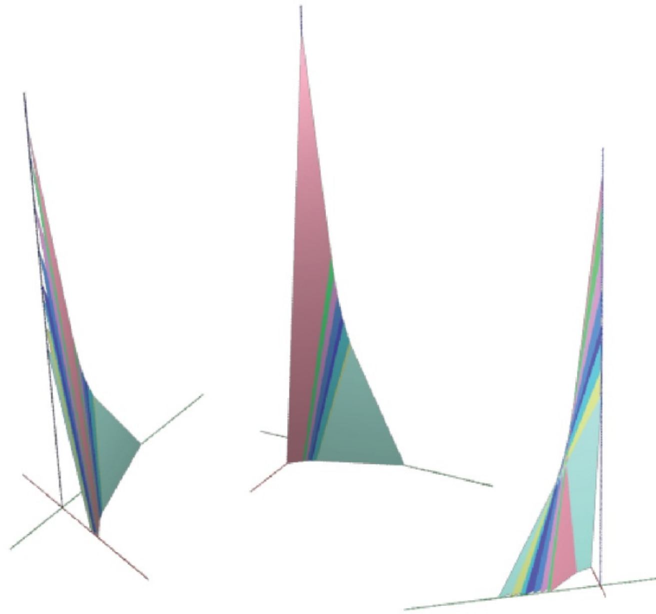
In search for a greater variation within the shape-notes themselves, it was conceived that there was a numbered relationship between all pitches of Western equal temperament, and this could be used as a tertiary constituent in defining their shape. Refer back to page 110 to see the Note-Frequency-Wavelength chart. Again, this chart contains all of the frequencies most commonly produced by Western-tempered instruments. Note that each pitch has been numbered as they sequentially rise in frequency. This tertiary constituent allocates a third point we can plot on a coordinate system, giving way to shape-notes that extend their two-dimensional properties into three-dimensional space. The images below depict the process in the creation of middle C (or C4).



Any number of shape-notes can be constructed using the same process. The image below depicts all of the shape-notes for the C-Major scale, rooted on middle C (C4), along with their corresponding frequency, wavelength, and relationship values.

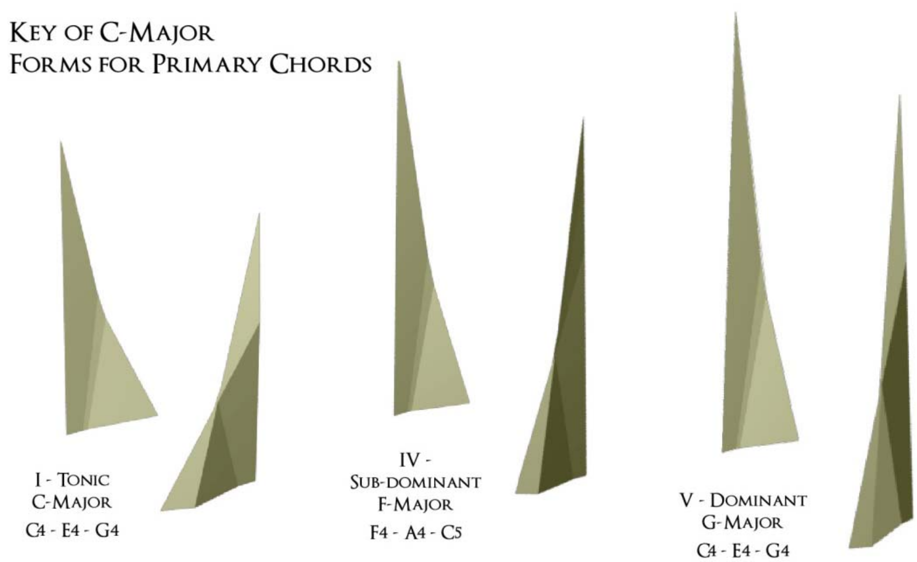


What sets these shape-notes apart from the previous is that all of them occupy their own space relative to their origin. Simply by constructing them from a common origin, the “Shape-Notes” create their own forms. The image on the proceeding page depicts the form created through the construction of the C-Major scale, rooted on middle C (C4).

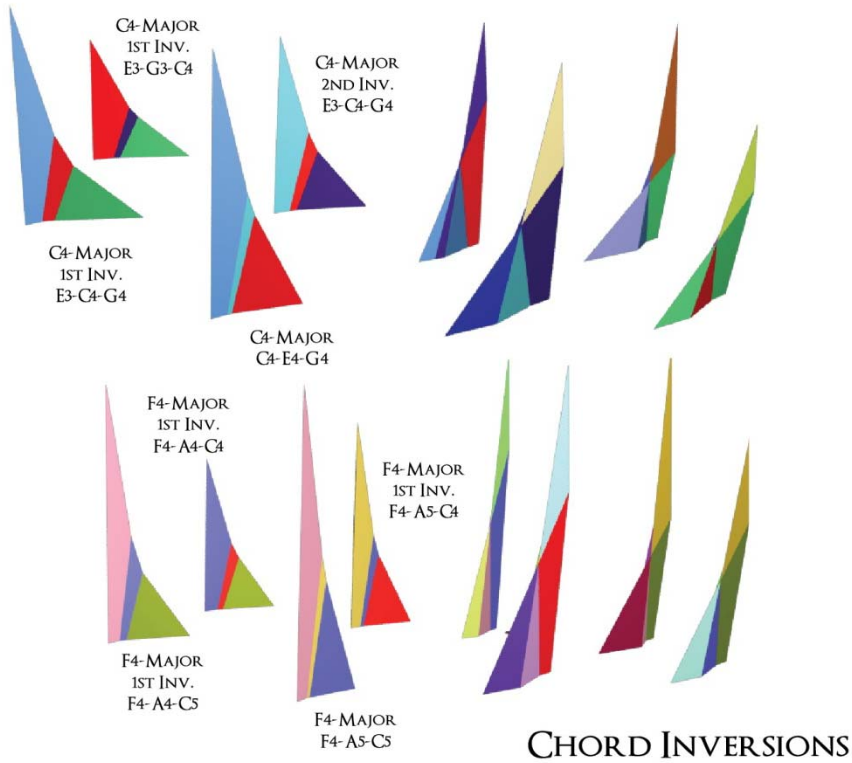


FORM FOR MAJOR SCALE OF MIDDLE C
C4 THROUGH C5

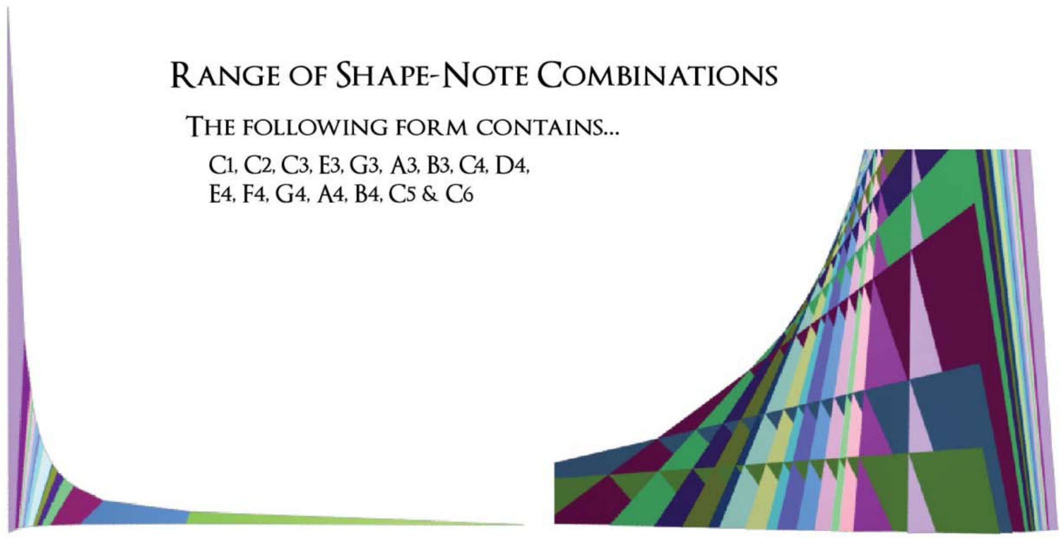
The same process can be used to construct the primary chords in the key of C-Major, those being C-Major, F-Major, and G-Major (image below). These are all triads; thus they are composed of three different shape-notes (listed below).



The following image illustrates inverted chord-forms of the primary chords in the key of C-Major.

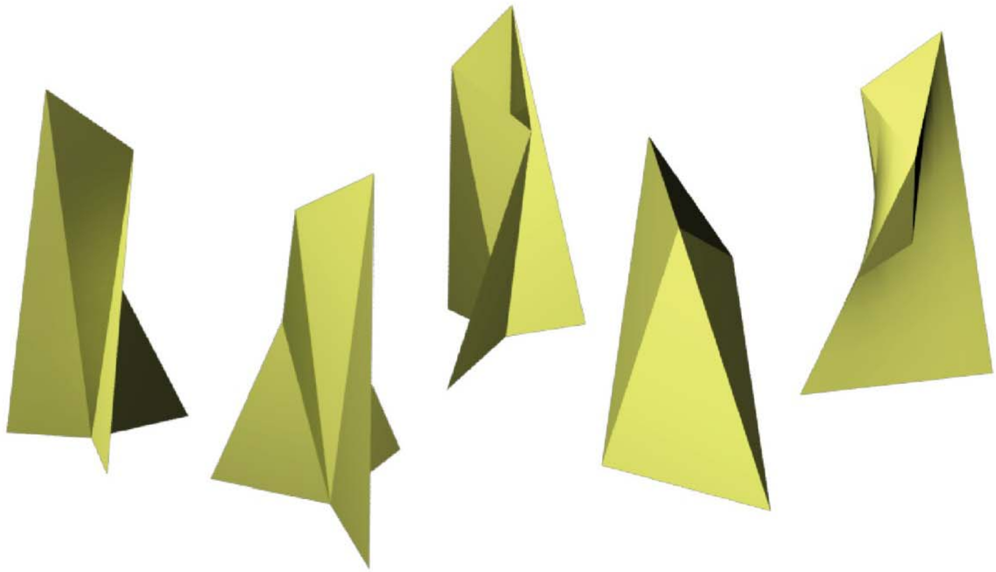


Using this technique, a physical rendering of any musical combination is possible. If a form were composed of every tone in the audible range, a smooth curve would dictate the inner profile. If frequencies from the just scale were used, an inverse relationship would be established between the change in frequency and the wavelengths. The resulting form would create a perfect hyperbola. The image on the following page depicts the form created through the combination of a wide range of shape-notes.

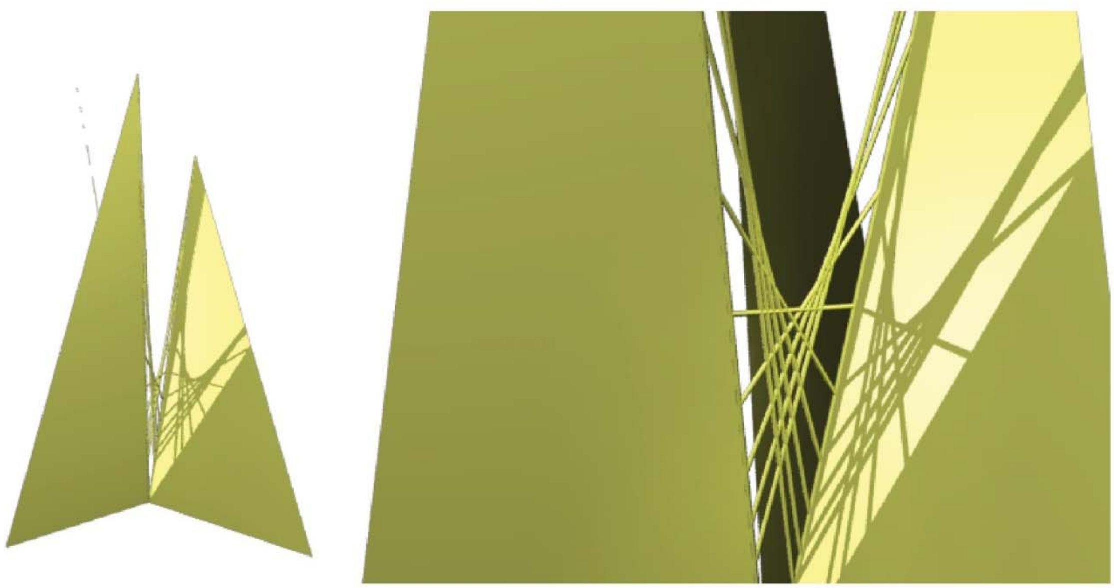


These shape-notes can also be applied to the 'Circle of Equal Temperament' to create a wide variety of "Chord-Forms." The following images illustrate some of the results in creating various chord forms and interval connections.

Shape-Note Variations
C-Major (C4 · E4 · G4)



SHAPE-NOTE VARIATIONS
C-MAJOR (C4 · E4 · G4)



SHAPE-NOTE · INTERVAL CONNECTION

The Building Block Theory converts the numerical values of sound into geometrical figures; any musical pitches can therefore be represented through a visual reference. The chord-forms of the Building Block Theory organize the shape-notes into a physical representation of harmony, and render a multitude of musical concepts in physical form. These forms are literally a physical representation of sound frozen in time; as such, they fall short in truly representing music, because they lack an expression of duration as a sequential change of events over time. However, every proportion and physical association within the chord-forms represents a relationship between the pitches of a musical chord, signifying key aspects of Western musical order. The Building Block Theory stands as a significant development in how music can render physical form.

A Melodic Experience

The "Melodic Experience" is an extension of the "Melodic Contour" exploration, combined with the idea of creating a generative form that represented a change in frequency over time, through an expansion and contraction of the forms surfaces. The melodic contour was adjusted to adequately represent the specific change in frequency and the duration of each musical pitch in alignment with the song's tempo and the average human walking speed. The adjusted contour was then revolved to create a walkable corridor, where the undulating surface of the form stood as a direct representation of the melody's fundamental components. The human perception of the intangible auditory devices of music were correlated to our visual perception of space. The primary correlation is our reaction to the aural proportions between sounds over time and the visual proportions of space and matter through time.

The image to the right depicts how the musical elements of frequency and duration are applied to the construction of the "Melodic Experience." This formula furnishes the user's perceptual experience by expressively evoking the similar tension-release patterns induced through the physics of sound, as articulated by a musical composition.

This study was initially tested on my original composition, "A Sunny Winter Day." Music notation served as the mediator between our auditory perception of the musical composition and the formation of the "Melodic Experience." The following image is the initial score of “A Sunny Winter Day,” depicting the melodic contour drawn over the primary melody of the song:

This song is written in F major, with a 4/4 time signature. The primary melody, written on the treble clef, is played in an *allegro* fashion at 120 beats per minute (BPM). The melodic contour was then adjusted to adequately represent the change in frequency and the duration of each musical pitch. Frequency interval proportions were used to adjust the vertical orientation of each point on the melodic contour. A horizontal line from each point was drawn with a length that corresponded the duration of each pitch to a person’s average walking speed. Based on a Portland University study of pedestrian walking speeds, the rate of 4 feet per second was selected as a person’s average walking speed.[108] A 4/4 time signature dictates that there are four beats per measure, with a quarter note receiving each beat. At a tempo of 120 BPM, each quarter

[108] Nick Carey and Karen Aspelin. "Draft Results: Establishing Pedestrian Walking Speeds,” Portland State University (May 31, 2005). http://www.westernite.org/datacollectionfund/2005/psu_ped_summary.pdf (accessed April 24, 2011).

note would sound for half a second. In alignment with an average walking speed of 4-ft/s, each quarter note receives a 2-ft. leaner segment (horizontal length on melodic contour). The diagrams below depict the numerical analysis of the melody, showing the calculations for frequency intervals, the formula for the beat's durational length, and the adequately adjusted melodic contour.

DURATION (SEC) : .25 .25 .25 .25 1 .25 .25 .5 1 .25 .25 .25 .25 .5 .5 .5 .5 1

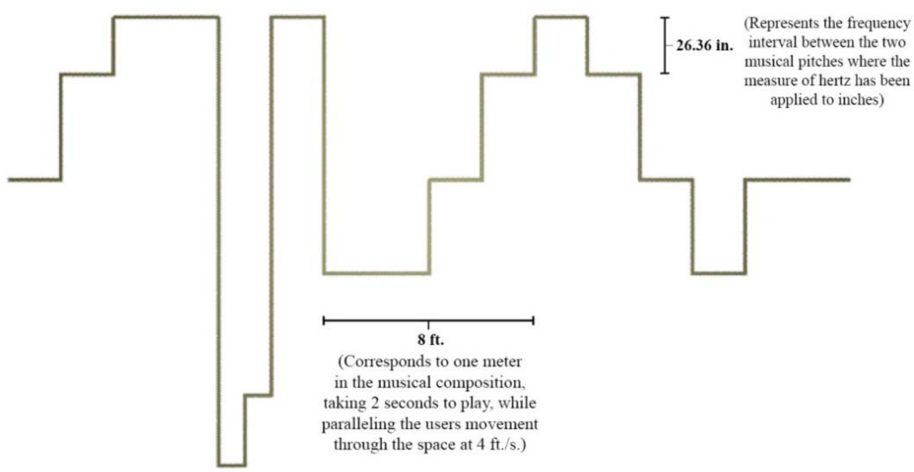
FREQUENCY (HZ) : 392 392 440 440 466.16 261.63 293.66 466.16 349.23 392 392 440 440 466.16 440 392 349.23 392

NOTES : G - G - A - A - B^b - C - D - B^b - F - G - G - A - A - B^b - A - G - F - G

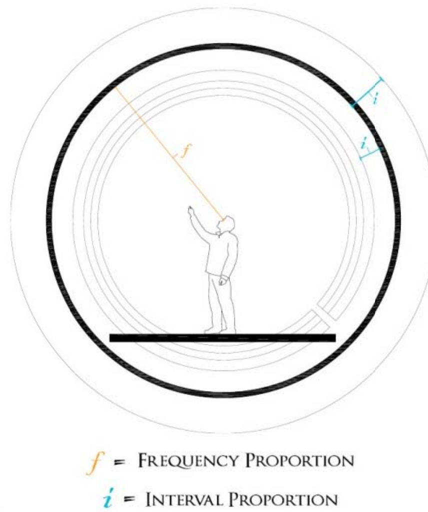
RELATIVE INTERVAL (HZ) : 0 +48 0 +26.16 -204.53 +32.03 +172.5 -116.93 +42.77 0 +48 0 +26.16 -26.16 -48 -42.77 +42.77

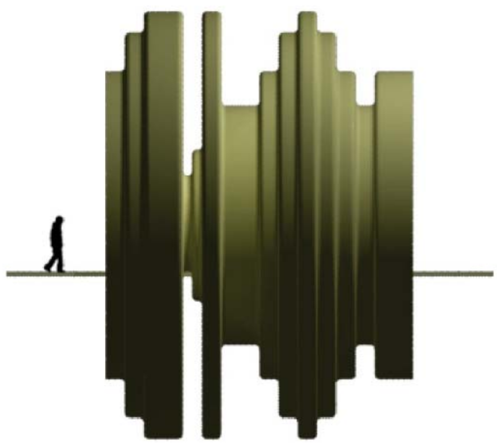
$$\text{BEAT'S DURATIONAL LENGTH (ft./beat)} = \frac{\text{AVERAGE WALKING SPEED (4 ft./sec.)}}{\text{TEMPO (BPM) / 60 (sec./min.)}}$$

ADJUSTED MELODIC CONTOUR



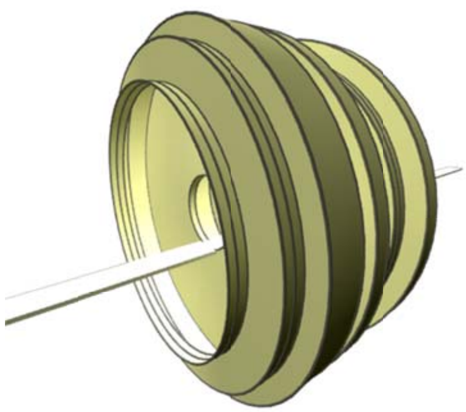
Once the melodic contour is adequately adjusted, it can then be used to create a three-dimensional form. To align our visual perception of the form with our auditory perception of the melody, the melodic contour was revolved around a horizontal axis to create a circular form, where the distance from the axis of revolution to the form's inner surface is equal in all directions. A walkable base plane was strategically inserted to align an average person's eye level with the axis of revolution. Considering both men and women, an average eyelevel is approximately 5'-4" high; for measurements that are more precise, please refer to the text *Architectural Graphic Standard*.

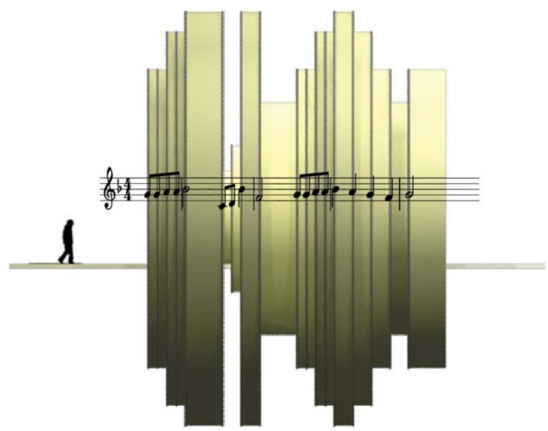




The visual experience of walking through this corridor parallels the auditory experience of listening to the songs predominant melody. The proportions between the surfaces of the form, the distance from eye level to the inner shell, the length between the form's undulation, and the rate at which a person experiences these changes in proportion all precisely reflect the perception of listening to the melody of “A Sunny Summer Day.”

The “Melodic Experience” expresses musical rhythm both visually and experientially. We see the rhythm of the melody expressed by the expansion and contraction of the form, heightened by experiencing the rhythm through a shift in spatial density. To enhance the musical rhythm of the form, a circular rib was added at every point a musical note would be struck. The images on the following page illustrate the musical rhythm of the “Melodic Experience.”

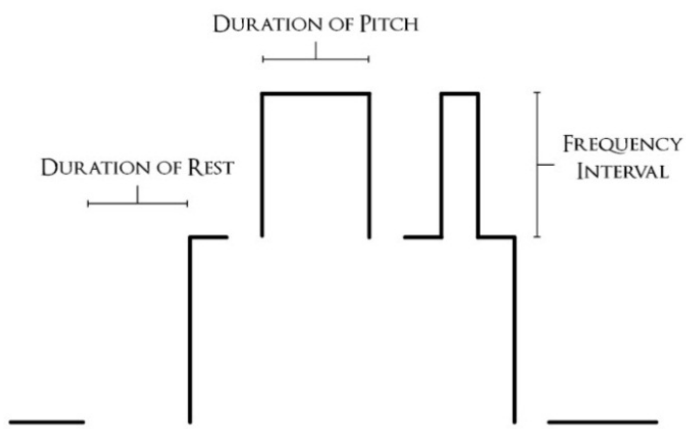




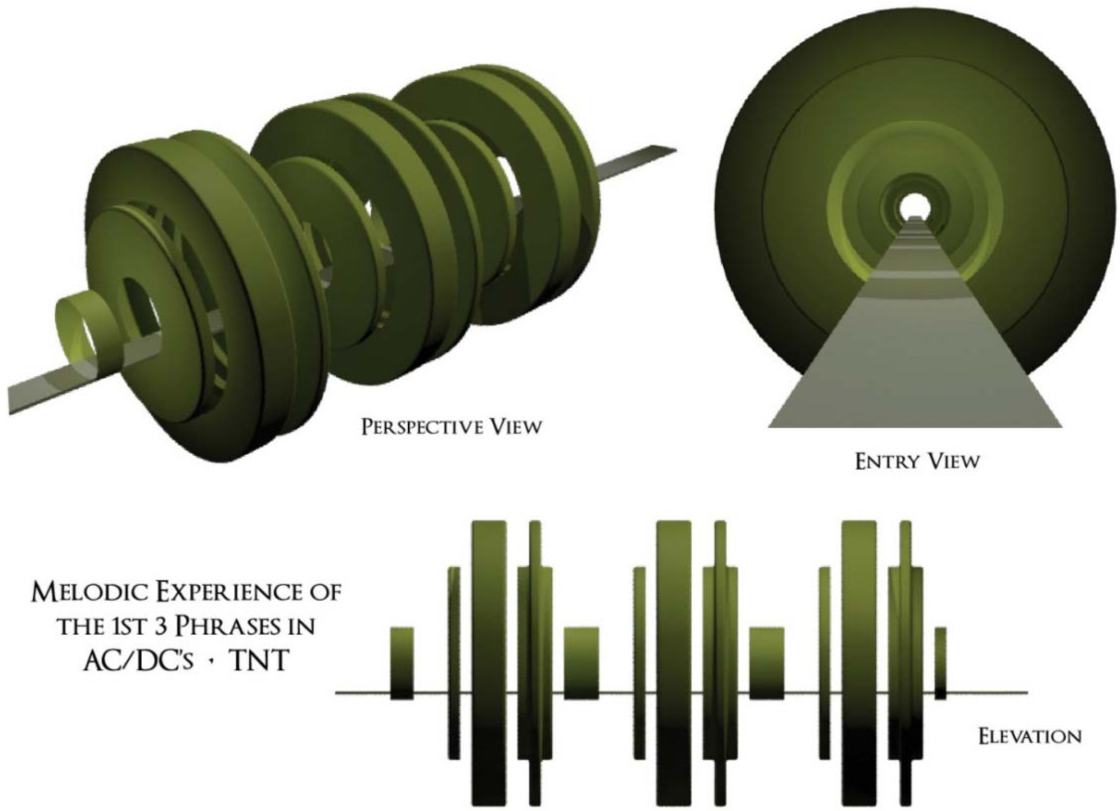
The “Melodic Experience” method of form-making was then tested using several musical compositions to evaluate its efficacy. Three alternate songs were specifically chosen for their variations in tempo, rhythm, and melody. The songs selected were “TNT” by AC/DC, “Let It Be” by The Beatles, and “B.Y.O.B.” by System of a Down. During the construction of each song’s “Melodic Experience,” minor adjustments were made to accommodate specific qualities of the song. The “Melodic Experience” method of form-making was not altered; it was only enhanced to adopt the qualities of musical rests and harmony.

The song “TNT,” by AC/DC, implements the use of rests between select musical pitches of the primary melodic line. The form of the “Melodic Experience” adapted to this technique by leaving gaps in the form, correlative to where musical rests take place in the melody. These breaks in the form are proportional to the duration of each musical rest, and were calculated using the invented formula for a “beat’s durational length.” The song is played at a tempo of 125 BPM, giving each beat a linear extrusion of 1.92 ft. The following diagrams depict the process of construction and the resulting form of AC/DC’s “TNT.”

AC/DC - TNT · Primary Melodic Line



Melodic Contour Adjusted to Represent Frequency Proportion & Beat’s Durational Length

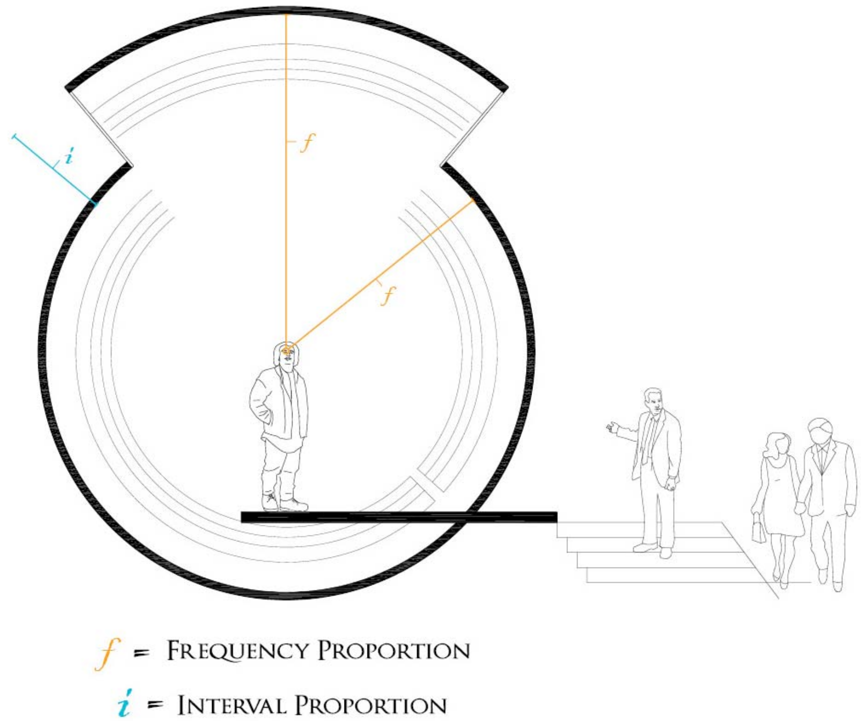


The primary melodic line of the song “Let It Be” by The Beatles, is a vocal melody. This melody is backed by a chord progression known as an accompaniment, introducing the element of harmony, multiple pitches sound simultaneously. The image below is the opening score of “Let It Be,” where the vocal melody and accompaniment are pointed out. The “Melodic Experience” adopted this element by creating two separate forms (one for the primary melody and one for the accompaniment) and combining them, where the accompaniment created the base of the form and the vocal melody created the top.

[109]

The diagram below depicts how our visual perception of the "Melodic Experience" is now reacting to two separate entities, representing a textural element of the song, and creating an experience that parallels our "polyphonic" perception of music.

[109] Lennon, John, and Paul McCartney. "Let It Be." *Online Sheet Music*. Sony/ATV Music Publishing, n.d. Web. 6 Oct. 2012. <http://www.onlinesheetmusic.com/let-it-be-p361927.aspx>.



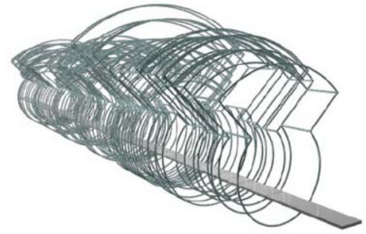
When multiple pitches sound simultaneously, the human ear perceives the pitch as an average of the sound's frequencies, yet the mind is able to distinguish the melody and the accompaniment as two separate entities.[110] Therefore, the frequencies of the pitches comprising the chords of the accompaniment were averaged to get a single numerical value for the radius of the base form. Because this song incorporates successive notes of the same pitch, a structural framing was integrated with the form to highlight the rhythmic nature of the song. "Let It Be" is played at a tempo of 70 BPM, giving each beat a durational length of 3.43 feet, making each quarter note almost twice

[110] Feilding, Charles. "Lecture 012 Hearing VII." College of Santa Fe Auditory Theory. http://www.feilding.net/sfuad/musi3012-01/html/lectures/012_hearing_VII.htm (accessed October 1, 2012); Deutsch, Diana. "Hearing music in ensembles." *Physics Today*, February 2010.#

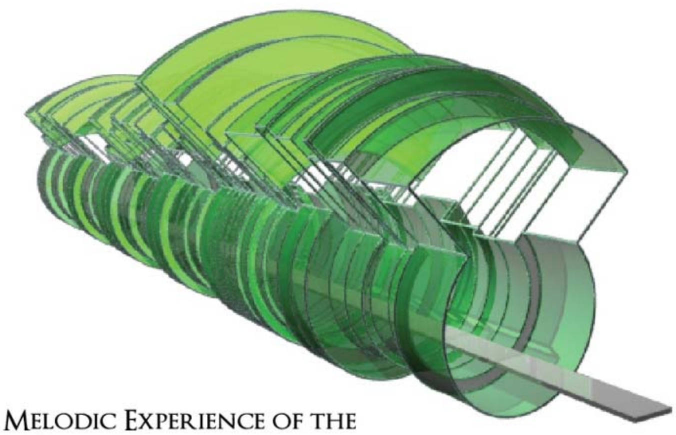
as long as those found in AC/DC's "TNT." The images below represent the combination of elements that formed the Melodic Experience of "Let It Be."

Vocal Melody

Accompaniment

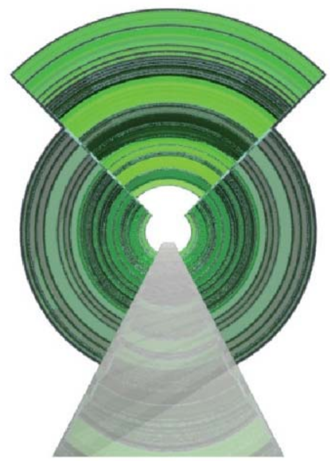


Rhythmic Framing

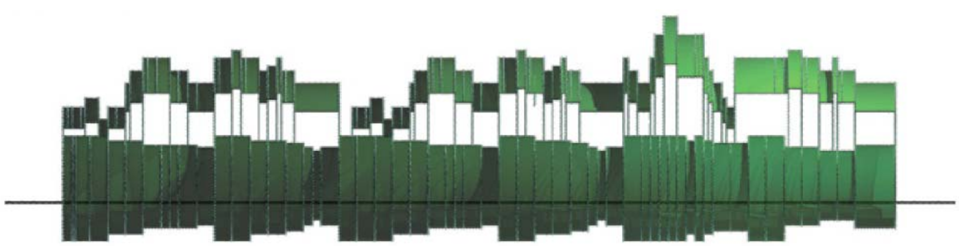


Melodic Experience of the First & Second Verses, and the Chorus in "Let It Be," by The Beatles

Perspective View

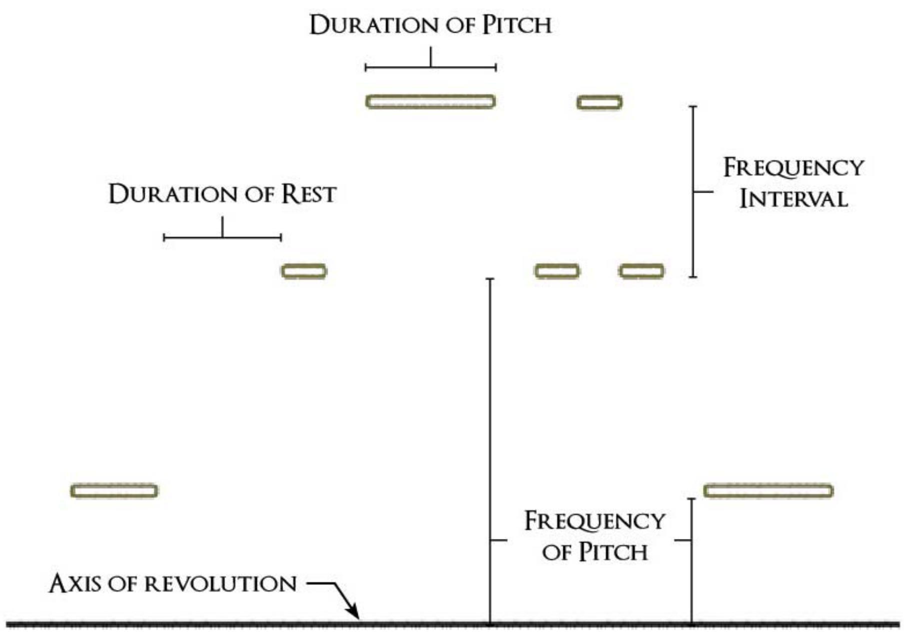


Entry View

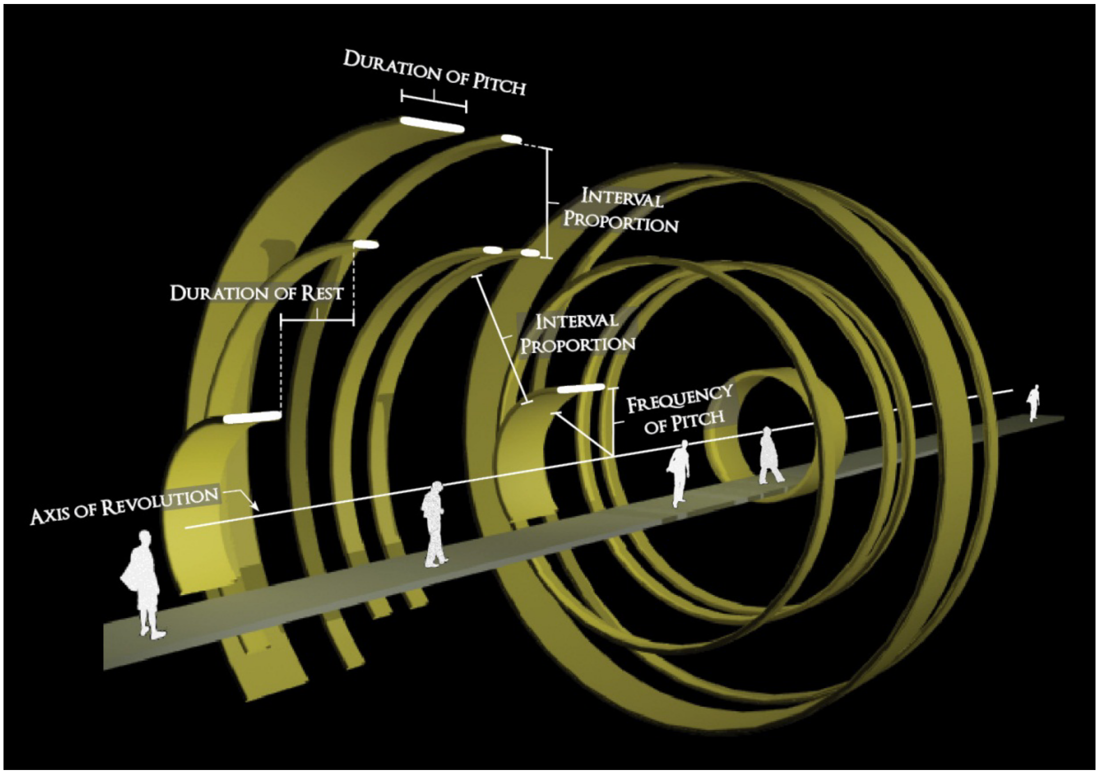


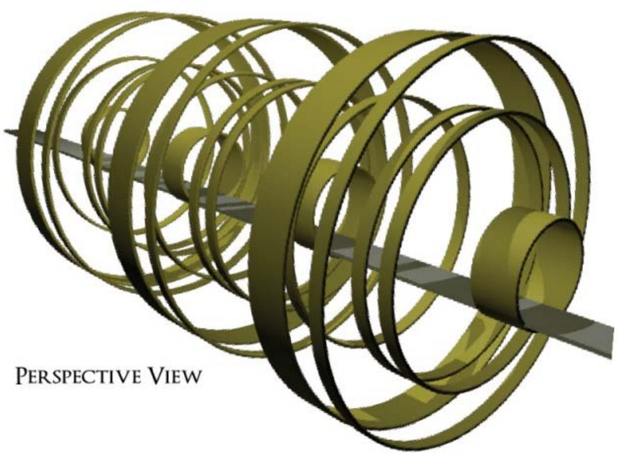
Elevation

A refinement was then tested on the melodic contour of AC/DC's "TNT," removing the vertical lines, so that the only physical elements left were those that represented the pitches of the melody. The horizontal lines were then replaced with 3-inch linear segments, where there length and relationship to one another embodied the melody's most essential elements: pitch duration, rest duration, frequency intervals, and pitch frequency from the axis of revolution at eye level. This catered to the user's overall experience by strictly linking the visual perception of the form to the auditory perception of the melody. The diagrams below depict this adjustment to the melodic contour and illustrate the overall perception of the form.



Linear Segments of Melodic Contour





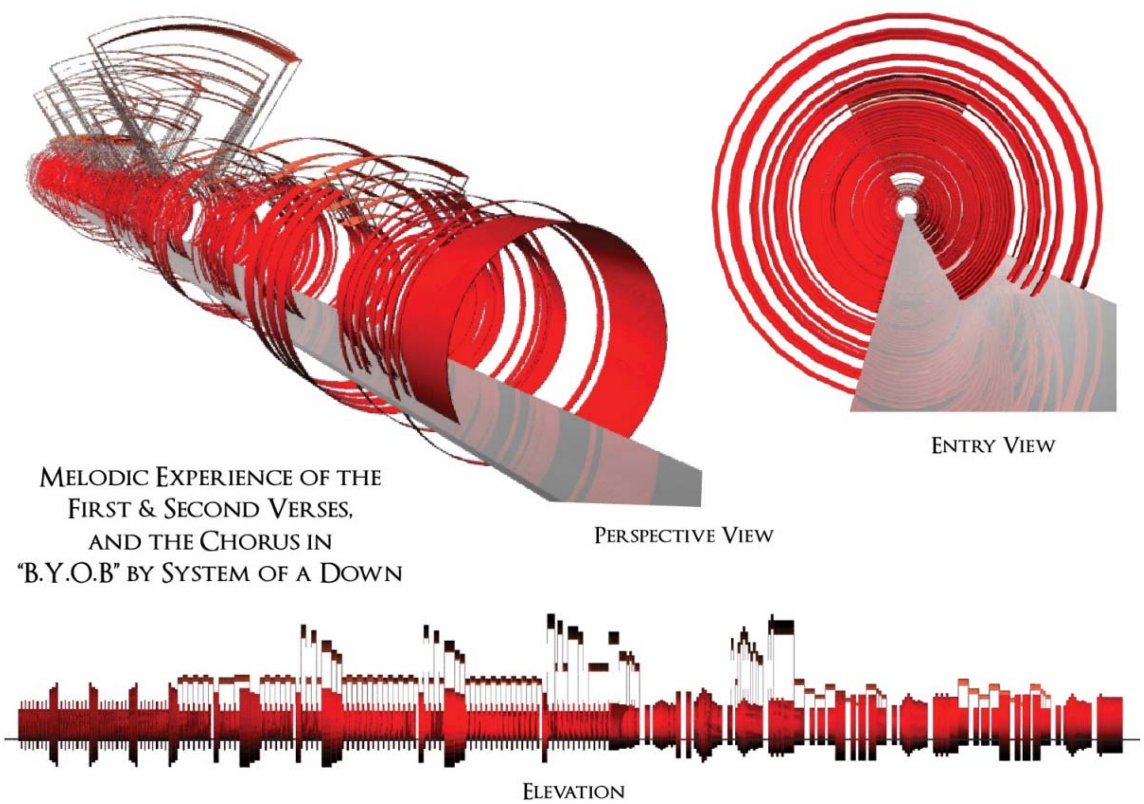
Perspective View

Entry View

Melodic Experience of
the 1st 3 Phrases in
AC/DC's · TNT

Elevation

The next song analyzed was “B.Y.O.B.” by System of a Down. “B.Y.O.B.” presents an intense rhythmic progression, played at an allegrissimo tempo of 160 BPM, while offering a wide variety of musical transitions. Like “Let It Be,” “B.Y.O.B.” relies heavily on the vocal melody to communicate its primary melodic structure; subsequently, this song’s Melodic Experience was constructed with an accompaniment as its base and the vocal melody as the upper portion of the form. In areas where the vocal melody drops out, the accompaniment takes over to create the whole form. The images below portray the Melodic Experience of System of a Down’s “B.Y.O.B.”



The Melodic Experience represents the proportion of pitch frequency in the distance from the center of revolution to the inner shell of the form. A change in this proportion takes place in forward motion, aligning the flux of pitch frequency with the duration of each pitch in a melody or a song. This combination of change in proportion over time is what establishes the "Melodic Experience" as

an effective translator of the primary elements of music: rhythm, time, and melody. Our audible perception and experience of music's primary elements have been directly correlated to our visual perception and experience of physical form and space.

Final Thoughts

At the completion of this thesis, the founding questions driving its investigation were reviewed. Do music and architecture coincide or sustain a vicarious relationship, if so, how? Can our physical experience and reaction to music, be replicated through our experience and perception of spatial relationships? Can musical notation be directly translated into a physical form? Are the fundamental components and theories that dictate musical order capable of formulating conceptual design?

The primary intersections of music and architecture were discovered through acoustical engineering, descriptive terminology, divine proportions, human reactions, and existing studies correlating the two mediums. Though some forms were suggested in the *Notation Formation* section, the written language of music primarily served as a translation device, creating a visual reference for our discernment of musical sounds. Facets of musical order are expressed through all of the investigations in this thesis; however, the *Building Block Theory* created conceptual forms, where every proportion and physical association represent a relationship between pitches of a musical chord, signifying key aspects of musical structuring. The *Melodic Experience* most successfully communicated the primary elements of music, because it directly linked our auditory perception of music, to our visual perception of space, as a function of time.

The application of proportions between musical pitches, as organized by Western music theory, to the proportions between physical objects in space, stands as the primary discovery of this thesis. Because the forms of the *Building Block Theory* and the *Melodic Experience* are founded on proportional relationships between musical pitches, they can be uniformly scaled to any size and maintain their expression of musical relationships.

This thesis unveils many of the intersections between the progressive mediums of music and architecture, and offers insight to new ideas in the conceptual realm of form making. May these methods resided as a pivot point for future endeavors of creative design, and inspire new perspectives on the overlapping languages of the world we live in.

Bibliography

AAC ~ The Audiology Awareness Campaign. "How We Hear: External, Middle & Inner Ear." Audiology Awareness Campaign. http://www.audiologyawareness.com/hearinfo_howhear.asp (accessed April 15, 2011).

Adair, John Eric. "Drift, wait and obey." In *The art of creative thinking how to be innovative and develop great ideas*. London: Kogan Page, 2007.

Association of Blind Piano Tuners, The. "History of Pitch." UK Piano Page. http://www.piano-tuners.org/history/pitch.html (accessed April 15, 2011).

Bain, Reginald. "The Harmonic Series." A Web-based Multimedia Approach to the Harmonic Series. www.music.sc.edu/fs/bain/atmi02/hs/index-audio.html (accessed April 17, 2011).

Ballora, Mark. "Pitch Vs. Frequency." Electronic Musician. http://emusician.com/tutorials/emusic_pitch_vs_frequency/ (accessed April 19, 2011).

Blumberg, Roger E.. "Blumberg's Music Theory Cipher for Guitar and Other Stringed Instruments." TheCipher.com. http://www.thecipher.com/index.html (accessed April 23, 2011).

Boretz, Benjamin. *Meta-variations: Studies in the foundations of musical thought*. New York: Open Space, 1995.

Bruce-Lockhart, Cullam. "Cadence and Harmony." cullam.com. http://www.cullam.com/teaching/cadence.htm (accessed April 15, 2011).

"Buddhist Architecture Design." this ARCHITECTURE. http://www.thisarchitecture.com/buddhist-architecture-design/ (accessed September 20, 2012).

"Cadence." Dictionary and Thesaurus - Merriam-Webster Online. http://www.merriam-webster.com/dictionary/cadence (accessed April 11, 2011).

Candler, David. "FREQUENCY PAINTING: 12 TONES." The Website of Artist Gary James Joynes. http://www.clinkersound.com/frequency-painting/?page_id=365 (accessed October 7, 2012).

Carey, Nick and Karen Aspelin. "Draft Results: Establishing Pedestrian Walking Speeds," Portland State University (May 31, 2005). http://www.westernite.org/datacollectionfund/2005/psu_ped_summary.pdf (accessed April 24, 2011).

ClassicalWorks. "Glossary of Musical Terms." Music History and Timeline at Classical Works.. http://www.classicalworks.com/html/glossary.html (accessed April 19, 2011).

comPADRE. "Sound Waves and Music." The Physics Classroom. http://www.physicsclassroom.com/class/sound/ (accessed April 19, 2011).

Conception. Dictionary.com. *Dictionary.com Unabridged*. Random House, Inc.http://dictionary.reference.com/browse/conception (accessed: November 28, 2010).

Concept. Dictionary.com. *Collins English Dictionary - Complete & Unabridged 10th Edition*. HarperCollins Publishers. http://dictionary.reference.com/browse/Concept (accessed November 28, 2010).

DB, Nate. "dentsu: paint sound sculptures." designboom. http://www.designboom.com/weblog/cat/10/view/11774/dentsu-paint-sound-sculptures.html (accessed October 7, 2012).

Delana. "Paint + Sound = Sculpture?." WebUrbanist . http://weburbanist.com/2011/05/11/paint-sound-sculpture-wild-photos-videos-included/ (accessed October 7, 2012).

Deutsch, Diana. "Hearing music in ensembles." *Physics Today*, February 2010.

Dorrell, Philip. "What is Music? Development: Statistical Structure of Human Speech Sounds and Calibration of Interval Perception." What is Music? http://whatismusic.info/developments/StatisticalStructure.html (accessed April 17, 2011).

Drexel University. "Math Forum: Ask Dr. Math FAQ: Golden Ratio, Fibonacci Sequence." The Math Forum. http://mathforum.org/dr.math/faq/faq.golden.ratio.html (accessed April 6, 2011).

"Ernst Florens Friedrich Chladni ." ILTweb. http://www.ilt.columbia.edu/projects/bluetelephone/html/chladni.html (accessed October 8, 2012).

Feilding, Charles. "Lecture 012 Hearing VII." College of Santa Fe Auditory Theory. http://www.feilding.net/sfuad/musi3012-01/html/lectures/012_hearing_VII.htm (accessed October 1, 2012).

Gaida , Ed. "History of U.S. Standard Pitch, A = 440 Hz." Mechanical Music Digest - Archives. http://www.mmdigest.com/Archives/Digests/199804/1998.04.05.05.html (accessed April 15, 2011).

Gardner, Helen, and Fred S. Kleiner. *Gardner's Art Through the Ages: The Western Perspective*. 13th ed., Student ed. Boston, Mass.: Wadsworth Cengage Learning, 2010.

"Glossary of Musical Terms." San Francisco Classical Voice. http://www.sfcv.org/learn/glossary/p (accessed April 19, 2011).

"Golden Ratio Media About Us ." Golden Ratio Media. http://goldenratiomedia.com (accessed April 6, 2011).

Harmony. Dictionary.com. *Dictionary.com Unabridged*. Random House, Inc. http://dictionary.reference.com/browse/harmony (accessed: April 17, 2011).

Jenny, Hans. "The BasicTriadic Phenomenon." In *Cymatics: A Study of Wave Phenomena and Vibration*. Newmarket, NH: MACROmedia, 2001.

Jones, George Thaddeus. *Music theory* . New York: Barnes & Noble Books, 1974.

Joynes, Gary James. "12 TONES « GARY JAMES JOYNES | FREQUENCY PAINTING SERIES." The Website of Artist Gary James Joynes. http://www.clinkersound.com/frequency-painting/?page_id=66 (accessed October 7, 2012).

Lennon, John, and Paul McCartney. "Let It Be." *Online Sheet Music*. Sony/ATV Music Publishing, n.d. Web. 6 Oct. 2012. <http://www.onlinesheetmusic.com/let-it-be-p361927.aspx>.

Logan, Jack, and Danlee Mitchell. "Elements of Music - Part One." Music in Our World. http://trumpet.sdsu.edu/M151/Elements_of_Music1.html (accessed April 22, 2011).

Lundkvist, Annika. "The Mandala in the Architecture of Sacred Space." Vajrayana Forms. http://usvajrayana.blogspot.com/2010/04/mandala-in-architecture-of-sacred-space.html (accessed September 20, 2012).

Martin, Elizabeth. *Architecture as a translation of music*. New York: Princeton Architectural Press, 1994.

"Marvin Minsky quotes." ThinkExist.com Quotations. http://thinkexist.com/quotes/marvin_minsky/ (accessed November 22, 2010).

McCarthy, Robert. *Sound Systems: Design and Optimization : Modern Techniques and Tools for Sound System Design and Alignment*. Oxford: Elsevier/Focal Press, 2007.

McGougal, Heather. "Cabinet of Wonders: The Wonder of the Golden Proportions." Cabinet of Wonders. http://cabinet-of-wonders.blogspot.com/2007/09/wonder-of-golden-proportions.html (accessed April 7, 2011).

Mid-South Community College. "MUSICAL TEXTURE." Shared Learning Objects. learn.midsouthcc.edu/LearningObjects/Music_Appreciation/musicaltexture/Musical_Texture.html (accessed December 6, 2012).

"Music and Architecture." NEXT.cc. http://www.next.cc/journey/discovery/music-and-architecture (accessed September 20, 2012).

Nave, Carl Rod. "Sound and Hearing." HyperPhysics. http://hyperphysics.phy-astr.gsu.edu/hbase/hph.html (accessed April 19, 2011).

Novak, Joseph D., and Alberto J. Cañas. "The Theory Underlying Concept Maps and How to Construct and Use Them." Institute for Human and Machine Cognition. http://cmap.ihmc.us/publications/researchpapers/theorycmaps/theoryunderlyingconceptmaps.htm (accessed November 20, 2010).

Peterson, Mark A. Lecture notes on, "The Vibrating String." Mount Holyoke College, South Hadley, Massachusetts . http://www.mtholyoke.edu/courses/mpeterso/galileo/interval.html (accessed April 18, 2011).

PhiPoint Solutions, LLC. "Phi - The Golden Number." GoldenNumber.net. http://goldennumber.net/index.htm (accessed April 6, 2011).

Pierce, John R. The Science of Musical Sound. Revised ed. New York, NY: W. H. Freeman, 1992

Read, Gardner. *Music Notation: A Manual of Modern Practice*. 2nd ed. New York: Taplinger Pub. Co./Crescendo Book, 1979.

Read, Gardner. *Pictographic score notation: a compendium*. Westport, Conn.: Greenwood Press, 1998.

"Seed Quotes." Joy of Quotes. http://www.joyofquotes.com/seed_quotes.html (accessed December 7, 2012).

Sethares, W. A. Tuning, Timbre, Spectrum, Scale. 2nd ed. New York, NY: Springer, 2005.

Sleeper, Harold Reeve, and Charles George Ramsey. *Architectural graphic standards* . Version 4.0 ed. Hoboken, NJ: John Wiley & Sons, 2007.

Smith, Greg J.. "Frequency Painting - Gary James Joynes Interview." Vague Terrain | Digital Art / Culture / Technology. http://vagueterrain.net/content/2011/01/frequency-painting-gary-james-joynes-interview (accessed October 7, 2012).

Solomon., Larry J.. "Solomon's Glossary of Technical Musical Terms." Solomons Music Theory Resources. http://solomonsmusic.net/glossary.htm (accessed April 19, 2011).

"Sound Sculptures | mcgarrybowen uk." mcgarrybowen london. http://www.mcgarrybowen.co.uk/blog/2010/09/28/sound-sculptures/ (accessed October 7, 2012).

"Steven Holl Biography." Archinnovations: Online Architecture Magazine. http://www.archinnovations.com/featured-architects/architects-profile/steven-holl-biography/ (accessed March 21, 2011).

"Stretto | Define Stretto at Dictionary.com." Dictionary.com. http://dictionary.reference.com/browse/stretto (accessed March 21, 2011).

"STRETTO HOUSE." STEVEN HOLL ARCHITECTS. http://www.stevenholl.com/project-detail.php?id=26&worldmap=true (accessed March 21, 2011).

Suits, Bryan H.. "Physics of Music - Notes." Michigan Technological University - Department of Physics. http://www.phy.mtu.edu/~suits/Physicsofmusic.html (accessed March 2, 2011).

"The Golden Section." Math-Kitecture. http://www.math-kitecture.com/golden.htm (accessed April 20, 2011).

Torben, Rees. "Ernst Chladni: physicist, musician and musical instrument maker." Whipple Museum of the History of Science, University of Cambridge. http://www.hps.cam.ac.uk/whipple/explore/acoustics/ernstchladni/ (accessed October 8, 2012)

UltraSloMo. "Creature in the Sonic Liquid." YouTube. http://www.youtube.com/watch?v=Yw4qklgNIxI (accessed October 7, 2012).

"What Is Music Theory?." Dummies.com; Making Everything Easier . http://www.dummies.com/how-to/content/what-is-music-theory.html (accessed April 20, 2011).

White, Gary C., David Stuart, and Elyn Aviva. *Music in Our World: An Active Listening Approach*. Boston: McGraw Hill, 2001.

White, Gary C. *Music first!* 5th ed. New York: McGraw-Hill, 2007.

"Xenakis as Architect." Iannis Xenakis. http://www.iannis-xenakis.org/xen/archi/real.html (accessed November 5, 2012).

Xenakis, Iannis, and Sharon E. Kanach.*Music and architecture: architectural projects, texts, and realizations*. Hillsdale, NY: Pendragon Press, 2008.